Chapter 5

Electronics

Accuwave Corporation

Expanding the Number of Light Signals in an Optical Fiber

Over the last two decades, the use of optical fiber as an alternative to metal wire and cable has exploded. Optical fiber is now the technology of choice for use undersea and for most terrestrial applications of more than the shortest distances.

More Light Signals Per Optical Fiber

This ATP project with Accuwave Corporation, a small California company specializing in the development of holographic communications systems, created a way to substantially increase the number of signals that can be transmitted in a single strand of fiber-optic cable. The new technology is designed to enable the transmission of 80 or more channels per fiber. If adopted, it could eventually reduce the cost per transmission and save hundreds of millions of dollars over a period of just a few years.

A Unique Holography-Based Approach

The new technology is based on the concept of wavelength division multiplexing (WDM), which transmits light of more than one wavelength through a single optical fiber, separating the individual wavelengths at the receiver. Such systems must discriminate among the different wavelengths and so are limited by the accuracy of the multiplexing and demultiplexing optics.

Accuwave had previously developed a unique approach to WDM using volume holography: holograms "written" in the interior of thick crystals of photorefractive (light-bending) materials. In the demultiplexer crystal, for example, multiwavelength light enters one end of the crystal and encounters a series of holographic gratings — each tuned to deflect a specific wavelength of light — that separate the light signals of different wavelengths. Accuwave had demonstrated the individual elements of a system that could multiplex wavelengths more than 10 times better than the current state of the art at visible wavelengths. With its ATP funding, Accuwave extended its technology to the infrared wavelengths used for long-distance telecommunications, and designed a prototype WDM system.

. . . multiwavelength light enters one end of the crystal and encounters a series of holographic gratings . . . that separate the light signals of different wavelengths.

Accuwave officials report that ATP funding enabled it to develop WDM for signal transmission, a task it would otherwise have been unable to do. In addition, receiving the ATP award helped the company form important alliances with research partners during the ATP project (not identified here for confidentiality reasons).

Marketing Disappointment Spurs Alternative Commercialization

Near the end of the ATP funding period, while Accuwave was trying to raise additional private capital to complete the technical work on its WDM system and sign commercialization agreements with potential customers, another company beat it to market with a competing system operating in the same infrared wavelengths. Nonetheless, Accuwave continued to work toward completion of its WDM multiplexer, which it believes provides multiplexing capabilities of higher signal accuracy, with more channels per fiber and in a smaller package than the products offered by competitors.

Though Accuwave did not succeed in its original commercialization plans for sale of a WDM system in the bulk-signal-transmission market, it launched several component products based on the ATP-funded technology. These include wavelength controllers, wavelength lockers and fiber-optic collimators, all of which are being sold to producers of WDM systems. The company developed contacts with potential telecommunications clients in Europe, Japan and Brazil, as well as the United States, and it planned to introduce its own wavelength multiplexers in the near future.

Potential Big Savings in Telecommunications

With its potential to increase the number of signals that a single optical fiber can carry, the Accuwave technology could significantly affect the cost of communications via fiber-optic cables, particularly if used for undersea applications. Because of the volume of messages transmitted via this medium, cost savings would be great, even if the number of signals per fiber were doubled. The Accuwave technology has the potential to double and redouble the number of signals per fiber many times

. . . another company beat it to market with a competing system operating in the same infrared wavelengths.

PROJECT:

To develop holographic-optics technology that will increase (by more than 10 times) the number of signals that can be transmitted through a single optical fiber.

Duration: 3/1/1993 — 3/14/1995
ATP number: 92-01-0055

FUNDING (IN THOUSANDS):

ATP	$1,987	69%
Company	898	31%
Total	$2,885	

ACCOMPLISHMENTS:

Accuwave developed a process for producing photorefractive materials suitable for fiber optics telecommunications applications. The company also:

- received two patents for technologies related to the ATP project:

  "Photorefractive Systems and Methods (Divisional)"

  (No. 5,684,611: filed 6/6/1995, granted 11/4/1997) and

  "Wavelength Stabilized Laser Sources Using Feedback From Volume Holograms"

  (No. 5,691,989: filed 9/14/1993, granted 11/25/1997);
- applied for two additional patents for technologies related to the ATP project;
- completed pilot production of wavelength division multiplexing (WDM) components designed for incorporation into equipment manufactured by other companies, and introduced the components in 1996;
- signed a purchase agreement with a major telecommunications equipment manufacturer;
- raised $4 million from venture capitalists and other investors since 1990; and
- built a plant and ramped up volume production in 1998.

COMMERCIALIZATION STATUS:

In 1996 and 1997, Accuwave introduced three WDM system components: wavelength controllers, wavelength lockers and fiber-optic collimators. The company continued to pursue its original goal of selling WDM products for fiber optics telecommunications applications.

OUTLOOK:

Despite the heretofore promising prospects for growing applications of this technology in the telecommunications sectors, the commercialization outlook at this time is bleak. As this report was going to press in late 1998, it was learned that the company had ceased operations and was in the process of declaring bankruptcy. While it is possible that the technology will be picked up by other companies and carried forward in the future, at this point there is insufficient information about the likelihood of this to comment further on the outlook.

COMPANY:

Accuwave Corporation
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Santa Monica, CA 90404

Contact: Neven Karlovac
Phone: (310) 449-5540

Number of employees:
5 at project start, 16 at the end of 1997

. . . launched several component products based on the ATP-funded technology.

. . . in late 1998 it was learned that the company had ceased operations and was in the process of declaring bankruptcy.

over, with the count possibly reaching as many as 80 signals per fiber.

In addition to applications in the bulk-signal-transmission market, the ATP-funded technology has the potential of providing greater cable bandwidth to homes and offices for use with high-definition TV and to the closed-circuit TV market, particularly for security uses. The company was interested in pursuing these potential applications, but instead used its resources to develop the WDM system for telecommunications applications. The technology also has potential applications in ultranarrow band filters, spectrometers and optical disk memories.

As this report was going to press in late 1998, it was learned that the company had ceased operations and was in the process of declaring bankruptcy. It is possible that the technology will be picked up by other companies and carried forward in the future.

AstroPower, Inc.

Manufacturing Technology for High-Performance Optoelectronic Devices

Optoelectronic devices — from light-emitting diodes (LEDs) and solar cells to lasers and detectors — are abundant in everyday life. Millions of LEDs are used in automobile dashboards and consumer electronic products (clocks, radios, VCRs, CD players, coffee brewers and microwave ovens), as well as in commercial and industrial products such as fax machines, copiers and printers.

A large area solar grade silicon sheet emerging from a silicon growth reactor which incorporates new ATP-funded technology.

LEDs That are Four Times as Bright

Although LEDs are used in many applications where digital readout is needed, they have limitations. They do not emit much light, so they cannot be seen at a distance. If they produced really bright light, LEDs would be even more widely used than they are already. This ATP project with AstroPower, a small Delaware company incorporated in 1989, developed a new approach to production-scale liquid-phase epitaxy (LPE). The company has fabricated LEDs in a way that significantly increases, by a factor of four, the brightness of the light they emit.

. . . made significant advances in understanding growth processes for compound semiconductor materials . . .

A New Approach

LPE is a widely used technique that involves melting a semiconductor material and letting it crystallize on a substrate. AstroPower's novel enhancement, the first technical goal of the project, involved the use of a thermal gradient that promotes the growth of the epitaxial layer laterally much faster than vertically from the substrate. Company researchers made significant advances in understanding growth processes for compound semiconductor materials and in applying LPE to lateral growth over buried reflectors and other components. The technology can be used for volume production of low-cost compound semiconductor devices — those made from a compound of elements, such as gallium arsenide, rather than a single element.

. . . succeeded in designing and assembling a modular prototype production growth system . . .

AstroPower's second technical goal was to develop the technology to automate the new LPE growth process in integrated factory-scale fabrication equipment. Company researchers succeeded in designing and assembling a modular prototype production growth system that has already significantly shortened production scale-up times for currently fabricated products, as well as for potential products under consideration by customers.

PROJECT:
To develop new crystal growth methods and high-throughput manufacturing technology for fabricating light detectors and emitters with integrated reflecting mirrors.

Duration : 7/15/1992 to 7/14/1995

ATP number: 91-01-0142

FUNDING (IN THOUSANDS):

ATP	$1,423	47%
Company	1,580	53%
Total	$3,003	

ACCOMPLISHMENTS:
The company achieved the goals of the ATP project: developing new epitaxial growth methods, as well as new processes for plant-scale industrial production operations. Evidence of the company's achievements are that it:

- received four patents related to the ATP project technology;

  "Columnar-Grained Polycrystalline Solar Cell and Process of Manufacture"
  (No. 5,336,335: filed 10/9/1992, granted 8/9/1994)

  "Hetero-Epitaxial Growth of Non-Lattice Matched Semiconductors"
  (No. 5,356,509: filed 10/16/1992, granted 10/18/1994)

  "Columnar-Grained Polycrystalline Solar Cell and Process of Manufacture"
  (No. 5,496,416: filed 8/5/1994, granted 3/5/1996)

  "Semiconductor Device Structures Incorporating "Buried" Mirrors and/or "Buried" Metal Electrodes"
  (No. 5,828,088: filed 9/5/1996, granted 10/27/1998)

- demonstrated the application of the new epitaxial production technology to optoelectronic device structures that have integrated reflecting mirrors for enhancing light output (an ultrabright light-emitting diode (LED) with buried reflectors), achieving a fourfold increase in brightness;
- completed scale-up of liquid-phase epitaxy (LPE)-growth technology to a high-throughput, production-scale process;
- significantly shortened production scale-up times for specific products, compared with previous manufacturing processes;
- constructed a demonstration production facility to implement the technology; and
- conducted an initial public offering of stock in February 1998, raising $16.7 million.

COMMERCIALIZATION STATUS:
Direct commercialization of ultrabright red LEDs, a proposed initial goal of the project, did not occur, mainly due to economic and market developments. Knowledge of new crystal growth methods acquired during this project contributed, however, to the enhancement of fabrication methods for the company's Silicon-Film™ solar cell and for other compound semiconductor devices.

OUTLOOK:
AstroPower has applied the ATP-funded crystal growth technology to its current manufacturing processes, improving productivity and lowering costs. It also plans to use the technology for several breakthrough devices when appropriate market size has been achieved; if such markets develop substantially, the outlook is promising. Two significant products that are nearing introduction are combustion sensors based on gallium-phosphorus compounds, and avalanche photodiodes and detectors based on indium-gallium-arsenic-antimony compounds.

COMPANY:
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Newark, DE 19716-2000

Contact: James B. McNeely
Phone: (302) 366-0400

Number of employees:
86 at project start; 160 at the end of 1997

Market Developments Upset Initial Commercialization Plans

Commercialization of the enhanced compound semiconductor devices in high volumes has not yet happened. An initial goal, to produce high volumes of red LEDs, has been stymied by market developments. The Japanese have come to dominate the market for red LEDs, which have become a commodity product. Although AstroPower has a technical advantage in producing the devices, the value of this market to the company is quite small, since the cost of entering the market is too high to make such a venture profitable.

Use of the Technology for Current Product Lines

Knowledge developed in the ATP-funded project, especially advances in understanding epitaxy technology, has proven useful across all company production activities, AstroPower officials say. They report that the company's product lines have all grown rapidly in recent years, and they attribute much of the growth to the ATP project. All of AstroPower's compound semiconductor-based products incorporate epitaxial growth in their fabrication. This includes their flagship product, the Silicon-Film™ solar cell. Silicon-Film™ is a continuous production process to manufacture crystalline silicon sheets and layers.

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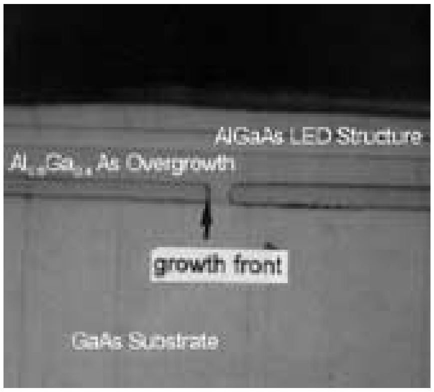
Shortened Production Scale-Up Times

The success of the ATP-funded project ensures that new and innovative optoelectronic devices will have significantly shorter production scale-up times than were possible before the project. The establishment of a technology that permits low-cost, high-throughput synthesis of compound semiconductor structures is potentially useful for many optoelectronic device products. It can be used, for example, in making specialty devices on a job-order basis using gallium arsenide, gallium arsenide-on-silicon, indium phosphorus and a host of other unexplored alloys. These devices are used in the fabrication of common products like detectors, solar cells, sensors and light-emitting products. The new technology can also be used in the production of highly sophisticated devices such as vertical cavity surface emitting lasers and resonant optical cavity detectors with back reflectors.

AstroPower intends to incorporate this technology in a number of breakthrough devices that it can produce in sufficiently large quantities when appropriate market size has been achieved. Two significant applications are nearing product introduction. The first is combustion sensors, based on gallium phosphorus compounds, that can be used for flame control in internal combustion engines and utility burners. The second is avalanche photo-



Cross-sectional photomicrograph of a light emitting diode showing device active layers and buried mirror overgrowth.

diodes and detectors, based on indium-gallium-arsenic-antimony and indium-arsenic-antimony-phosphide compounds, that can be used for light direction and range instruments, collision avoidance, atmospheric gas measurements, weather prediction, spectroscopy, blood gas analysis and noninvasive medical analysis. These two products are currently in pilot production and are being tested by NASA, the Air Force and industrial companies.

An initial goal, to produce high volumes of red LEDs, has been stymied by market developments . . . red LEDs have become a commodity product.

Company Growth

At the beginning of the ATP project in 1992, AstroPower had annual product sales of $1 million. By 1997, sales had grown to $16 million. And in February 1998, AstroPower successfully conducted an initial public offering of stock, raising $16.7 million.

AstroPower is convinced that had it not conducted the ATP-funded project, its growth experience (as measured by product sales) would have been set back by three years, the length of the ATP project. This belief is based on the use of improved epitaxial growth technology across all of its product lines, its application of manufacturing automation processes to all of its manufacturing operations, and to the overgrowth of semiconductor materials on dissimilar substrates as well as on mirrors, insulators, and conducting planes. Without the ATP funds, AstroPower says it would not have carried out the project.

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Potential Large Economywide Benefits

AstroPower noted at the beginning of its ATP project in 1992 that it expected in a project like this that products might take as long as 10 years to move from initial technology development to new product sales. The demonstration production facility AstroPower developed is capable of producing millions of LEDs or other LPE-based optoelectronic devices per month. When sufficient demand for the new products emerges, AstroPower plans to construct an optoelectronic semiconductor chip-manufacturing facility for new products made possible by the innovative LPE-growth technology.

Benefits are already accruing to purchasers of the company's solar cells, which have higher quality and cost less than they did before the ATP project. If the company succeeds in bringing to market additional products that use the new technology, even more benefits will accrue to its customers. Because of substantial uncertainty about these events, it is too speculative at this time to try to predict the magnitude of these future benefits.

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Cree Research, Inc.

Processes for Growing Large, Single Silicon Carbide Crystals

Most computer chips today consist of tiny electrical and electronic components on a thin slice of silicon crystal. As many as 5 million discrete components can be placed on a piece of crystal less than 2 inches square. Silicon crystal chips, however, are quite sensitive to heat. Electricity passing through a chip's super-thin connecting wires creates heat, just as it does in the heating element of a toaster. If too much heat builds up, the chip loses its functionality.

Cree's LED chips are used by Siemens A.G. for back lighting for this dashboard.

Beating the Heat in Electronic Devices

This ATP project with Cree Research, a small company in North Carolina's Research Triangle Park, made significant progress in the development of an alternative raw material for making crystal slices — silicon carbide. This material belongs to a class of semiconductors having "wide bandgap," which means they are relatively insensitive to increased temperatures. Silicon carbide's thermal conductivity is greater than that of copper, so it rapidly dissipates heat. It is impervious to most chemicals and highly resistant to radiation. Silicon carbide is extremely hard — it is used as grit in common sandpaper — indicating that devices made with the substance can operate under extreme pressure. It also possesses high field strength and high saturation drift velocity, characteristics suggesting that devices made of it can be smaller and more efficient than those made of silicon.

. . . full-color LED displays become possible with the existence of blue LEDs, as blue was a missing primary color.

Cree and others have shown that, even at red-hot temperatures, silicon carbide devices maintain functionality. Some of them, in fact, have continued to operate at 650 degrees Celsius. The wide bandgap also allows silicon carbide devices to operate at shorter wavelengths, enabling the creation of blue light-emitting diodes (LEDs) that could not be made from silicon. Moreover, full-color LED displays become possible with the existence of blue LEDs, as blue was a missing primary color.

Growing Large Crystals to Reduce Costs

Cree was founded in 1987 to commercialize silicon carbide and began by making LEDs on a silicon carbide substrate. Prior to its ATP project, Cree was already the world leader in silicon carbide technology and had been making 1-inch-diameter silicon carbide crystals. But progress in the development of devices based on silicon carbide had been stymied by difficulties in growing large, high-quality single crystals, a bottleneck that led Cree to pursue more research.

During the ATP project, Cree advanced silicon carbide technology by developing methods to greatly reduce the amount of imperfections in crystals and to increase their size to two inches or greater in diameter. Larger-diameter crystals result in lower production costs, which

The *Real Color Display*™, a moving sign which is capable of displaying the full range of colors, made possible by the use of blue LEDs.

PROJECT:
To substantially reduce the cost and improve the durability of light-emitting diodes (LEDs) and other electronic and optoelectronic devices by increasing the quality and size (to 2 inches or more) of silicon carbide (SiC) single crystals.

Duration: 6/15/1992 — 6/14/1994
ATP number: 91-01-0256

FUNDING (IN THOUSANDS):

ATP	$1,957	82%
Company	435	18%
Total	$2,392	

ACCOMPLISHMENTS:
Cree essentially met or exceeded all of the technical milestones. Successful development of the technology is indicated by the fact that the company:

- applied for one patent on technology related to the ATP project;
- presented several papers at professional conferences;
- raised $13.2 million via an initial public stock offering in February 1993;
- made high-quality, 2-inch SiC wafers, greatly opening up the blue LED and SiC wafer markets;
- raised approximately $17.5 million in a private stock offering in September 1995;
- increased annual revenues from $3 million at the start of the ATP project in 1992 to $7.5 million at the end of the ATP award period in 1994;
- received $5.8 million from the Defense Advanced Research Projects Agency in May 1995 for further development of silicon carbide growth processes to support production of 3-inch wafers;
- formed Real Color Displays, a wholly owned subsidiary, to exploit this technology for full-color LED displays;
- received a $6 million order in September 1996 from Siemens for blue LEDs; and
- supplied the SiC wafers for components in the SiC solid-state transmitter used by Westinghouse Electric to make the first U.S. commercial-scale high-definition TV (HDTV) broadcast in April 1996.

COMMERCIALIZATION STATUS:
The larger SiC wafers, made with the ATP-funded technology, are being used in the fabrication of blue LEDs sold to many industrial customers. The wafers are also being provided in limited quantities for development projects in government and industry research laboratories.

OUTLOOK:
The improved processing technology makes the outlook for the commercial use of SiC crystals highly promising. The cost of producing blue LEDs has already been reduced substantially, and the expected widespread commercial availability of larger-diameter SiC wafers promises a new range of applications, including HDTV transmitters. Benefits in the form of lower costs and higher quality will accrue to industrial users of blue LEDs and SiC wafers, as well as to consumers who use devices containing these two Cree products.

COMPANY:
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Durham, NC 27713

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Phone: (919) 361-5709

Number of employees:
41 at project start, 210 at the end of 1997

. . . devices that were impractical to make with pure silicon can be made with silicon carbide.

are crucial to opening markets for silicon carbide devices. The company also developed ways to significantly improve the doping (adding impurities to achieve desired properties) and epitaxial deposition (growing one crystal layer on another) processes for silicon carbide. Improving doping uniformity directly increases production yield and thus reduces costs.

Cree's success with the ATP project enables the fabrication of electronic devices that can operate at much higher temperatures and withstand high power levels. Silicon carbide components used in experimental high-definition television (HDTV) transmission, for instance, delivered more power, lasted longer and cost less to produce than conventional silicon-based components. Now equipment that was costly to manufacture (owing to the need for heat-dissipation systems) can be produced less expensively, and devices that were

Cree's success with the ATP project enables the fabrication of electronic devices that can operate at much higher temperatures and withstand high power levels.

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New Products: Blue LEDs and Silicon Carbide Wafers

The ATP project has been highly productive for Cree and the economy at large. The company has used the new technology to produce larger silicon carbide wafers to use in its fabrication process for blue LEDs. It is also offering the larger silicon carbide wafers for sale to other companies.

Cree is using the ATP-funded technology to reduce the cost of producing blue LEDs, and their sales have increased substantially. Production cost is primarily a function of the number of wafers processed. If wafer size can be increased dramatically, the cost per device will decrease dramatically because so many more devices can be made on a wafer. The silicon carbide wafer technology is also aimed at markets for other blue light-emitting optoelectronic devices, optical disk storage, microwave communications, and blue and ultraviolet laser diodes, as well as high-temperature, high-power and high-frequency semiconductors.

Benefits for the Economy

Benefits from the new silicon carbide technology are already accruing to customers who have bought large volumes of blue LEDs or silicon carbide wafers to use in their own production. Performance measures (resistance, power output, sensitivity to light, operating temperature) for silicon carbide devices are frequently large, relative to available alternatives. Economic benefits from these performance improvements spill over to other producers involved in fabrication and assembly before a wafer-based product reaches the end user. The total of these incremental benefits is expected to be much larger than the profits Cree receives for selling the silicon carbide wafers.

Cree's private success has led to public benefit, which is expected to grow as the number of applications for larger silicon carbide wafers increases. Westinghouse, for example, used Cree's silicon carbide wafers in fabricating components for the transmitter it used in the first commercial-level HDTV broadcast in the United States, in 1996. Westinghouse said its transmitter can deliver three times more power, has longer life and costs less to produce than conventional silicon-based transmitters. Although the number of HDTV transmitters that will use silicon carbide wafers is unknown at this time, widespread use of this technology in HDTV broadcasting could produce large general economic benefits if it speeds commercialization of HDTV.

ATP Advantages

Cree reports it was attracted to the ATP as a funding source for the development of the bulk crystal and epitaxial growth technologies because the company could retain its process technology knowledge. The ATP award also helped Cree form alliances with research partners and speed the development work, enabling the company to get results about 18 months sooner than it would otherwise have been able to do. During the course of its two-year ATP project, Cree also grew significantly.

Company officials say the success of the ATP-funded project was primarily responsible for a subsequent award of $5.8 million from the Defense Advanced Research Projects Agency (DARPA) to further develop silicon carbide growth processes to produce 3-inch wafers. If wafer size can be increased to 3 inches, the cost per device will drop even further. This DARPA project got under way in May 1995.

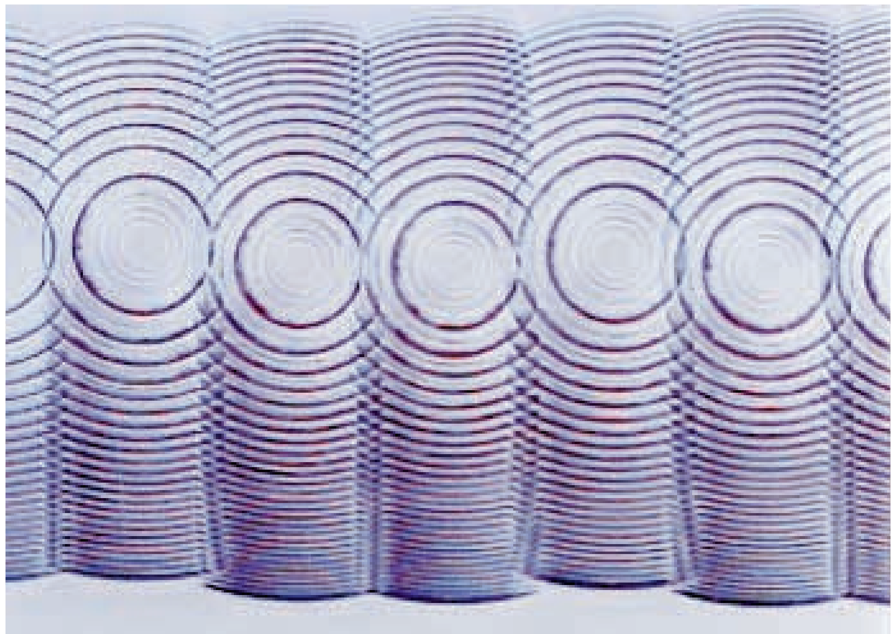
. . . silicon carbide wafers . . . used in the first commercial-level HDTV broadcast in the United States . . .

The low-cost blue light emitting diode (LED) produced with new silicon carbide crystal technology.

Cynosure, Inc.

Harnessing Cheap Diode Lasers to Power a Low-Cost Surgical Laser

Surgery is performed tens of millions of times a year in the United States, and it is usually a painful, risky procedure for the patient. It is also risky for the surgeon in terms of malpractice liability. Patients, surgeons and health insurance companies are constantly looking for new, less-invasive procedures to replace conventional surgery. Laser surgery is a prime candidate. One problem that limits this approach, however, is the price of equipment. A typical 100-watt surgical laser costs about $700 to $1,000 per watt of laser output, or about $70,000 to $100,000.



Photomicrograph of an array of multi-level diffractive lenses, fabricated with a 193 nanometer excimer laser.

A Laser for Lower-Cost, Less-Invasive Surgery

This ATP project with Cynosure, founded in 1991, was designed to develop a smaller, less-expensive laser source for surgery and other applications. The idea behind the Cynosure laser system — which was expected to sell for about $150 to $200 per watt of laser light delivered at the end of a surgical optical fiber — is based on harnessing the light from an array of 200 semiconductor, or diode, lasers. The problem with this approach in the past has been the difficulty of exactly aligning all 200 beams before they go into the diffractive optics transformer that collimates them into one tight, powerful beam. Minor inaccuracies in the alignment of the individual lasers can greatly degrade the performance of the system.

Cynosure's innovation was to develop an automated system to custom-mill arrays of 200 corrective lenses to match arrays of 200 diode lasers. In such a system, diagnostic equipment measures the alignment error of each laser beam and feeds the results to a computer, which drives a powerful laser that mills the lens array in less than 10 minutes. The result is a customized lenslet array that corrects the beams before they enter the transformer.

Barriers to Commercialization

Cynosure successfully designed and built a customized lenslet array to correct the beams from an array of 200 diode lasers. The researchers, however, failed to build a system that could generate the target power level — 20 watts of laser light from a medical optical fiber — because the company was unable to secure an adequate, low-cost supply of a low-tech component: a collimating array. The intended supplier, which was the sole source of the collimating array, stopped making the device and sold its production division. The new owner also chose not to produce the array.

The researchers, however, failed to build a system that could generate the target power level . . .

To make use of some of the technology developed in the ATP project, Cynosure is collaborating with the Lincoln Laboratory at Massachusetts Institute of Technology and using about $100,000 from the Small Business Technology Transfer Program to develop a "low-cost diode-laser system for treatment of arrhythmia" for the National Heart, Lung and

PROJECT:
To design an optical system for collecting, aligning and combining beams from an array of semiconductor lasers into one powerful beam, an achievement that will lead to the development of smaller, cheaper lasers for surgery and other applications.

Duration: 5/1/1993 — 4/30/1995
ATP number: 92-01-0136

FUNDING (IN THOUSANDS):

ATP	$1,965	49%
Company	<u>2,067</u>	51%
Total	$4,032	

ACCOMPLISHMENTS:
Cynosure designed and built a fault-tolerant optical system for a diode-laser array but was unable during the project to obtain a laser beam with the targeted 20 watts of output from a medical optical fiber. Later, the company achieved this goal with an alternative approach built, in part, on the knowledge developed during the ATP project. The company:

- received one patent for technology related to the ATP project:

  "Fault-Tolerant Optical System Using Diode Laser Array"

  (No. 5,369,659: filed 12/7/1993, granted 11/29/1994);
- published a paper on its research findings;
- was ranked number 112 in the 1996 *Inc.* magazine list of the 500 fastest-growing private companies in America;
- increased its sales from $626,000 in 1991 to more than $23 million in 1997; and
- is collaborating with Lincoln Laboratory and using funds from the Small Business Technology Transfer Program to develop a "low-cost diode-laser system for treatment of arrhythmia," based on the ATP technology, for the National Heart, Lung and Blood Institute.

COMMERCIALIZATION STATUS:
Commercialization was stymied by Cynosure's inability to secure the supply of a critical part at an affordable price. Since the ATP project ended, the company has taken a different, less-sophisticated approach to building a commercializable medical laser, using its own funds. That device has achieved the 20-watt ATP goal, and the company is scaling it to achieve 200 watts output. Commercial lasers are scheduled for market introduction in the near future.

OUTLOOK:
The benefits originally expected from commercialization of the ATP-funded technology should be realized via commercialization of the alternative technology that built on the technical knowledge developed in the ATP project.

COMPANY:
Cynosure, Inc.
10 Elizabeth Drive
Chelmsford, MA 01824

Contact: Horace Furumoto
Phone: (978) 256-4200

Number of employees:
30 at project start, 120 at the end of 1997

Informal collaborator:
Massachusetts Institute of Technology, Lincoln Laboratory

Blood Institute. The company is proposing to extend the scope of the project to include other conditions, besides arrhythmia, that can be treated with minimally invasive surgery. This new project is based in part on the demonstration that the ATP-funded technology, as modified by the company, is capable of delivering 10 watts of power into a 100-micron fiber-optic tube.

Alternative Approach

After the ATP project, Cynosure investigated alternative techniques, based on commercially available components, to channel the many beams from diode-laser arrays into a surgical optical fiber. The company found this can be done by grinding a hyperbolic lens onto the end of a small optical fiber, fitting one such fiber to each diode and stacking the fiber-coupled diodes into a two-dimensional array, as the ATP proposal had suggested. The fibers take the place of the diffractive optics in the proposed ATP laser system, with the tiny lenses directing the output from the diode array into a single fiber.

The company's switch to a different technological approach using readily available parts to concentrate the laser beams allowed commercialization to resume. Commercial lasers are now scheduled to be available in the near future.

Mission Accomplished

Lower-cost, higher-power medical diode lasers are a necessity for minimally invasive surgery, and it is said that necessity is the mother of invention. Cynosure invented the approach using fiber-coupled lasers, which are manufactured using standard optical fabrication methods and readily available components. The company expects this approach will not only reduce the cost of medical lasers but will also cost less than the diffractive optics-combiner approach envisioned by the ATP project.

By significantly reducing the cost of surgical lasers, the Cynosure technology would enable wider use of minimally invasive surgery, reducing hospitalization times and lowering health-care costs. For example, gall bladder removal by conventional surgery requires a 4- to 6-inch incision that results in four to seven days of hospitalization and a month of recovery time. When the removal is done by laser via a fiberoptic scope inserted through a small incision (a procedure already in widespread use), the patient is hospitalized for only two or three days and recovers much faster. Less-costly medical lasers would likely increase gall bladder removal by laser.

Funding from the ATP allowed Cynosure to perform research and development work it would otherwise have been unable to do. The award enabled it to hire highly qualified optical physicists to conduct the research on diffractive optics, and to develop the technical capability needed for future manufacture of diffractive optics devices. Cynosure is currently considering licensing this technology to a company whose core business is diffractive optics. In addition, the availability of highly sophisticated optical diagnostic equipment allowed Cynosure to better understand and test the fiber-coupled equipment it is developing for the commercial sector.

The company's switch to a different technological approach using readily available parts to concentrate the laser beams allowed commercialization to resume.

Diamond Semiconductor Group, LLC (DSG)

Lowering the Cost and Improving the Quality of Computer Chips

Worker holding the world's first 300 millimeter silicon wafer populated with electronic components using the wide beam ion implantation technology.

Billions of integrated circuits — the tiny chips that run personal computers and thousands of other electronic devices — are fabricated every year in the United States through ion beam implantation, a technique for introducing carefully controlled impurities, or dopants, into specific locations on the semiconductor wafers from which chips are cut. Dopants control the electrical properties of the semiconductor, forming the transistors and other microscopic components of each chip.

Ion Beam Implantation for 300-mm Wafers

With chip components getting smaller and denser, the need for more accurate control of dopant implantation has risen. At the same time, competitive manufacturing has driven the size of production wafers up, making increased accuracy problematic because of the difficulty in precisely scanning the implantation beam across the wafer.

This ATP project allowed Diamond Semiconductor Group (DSG), a two-person start-up company when it applied to the ATP, to develop a new and better way to implant dopants on large silicon crystal wafers measuring 300 mm or more in diameter, compared with the previous industry standard of 200 mm. Because the area of a 300-mm wafer is 2.25 times that of a 200-mm wafer and some waste always occurs at wafer edges, the new approach enables the production of about 2.5 times as many chips from a single wafer as the 200-mm technology can make. The use of DSG's new technology in production equipment makes it possible to lower the cost and improve the quality of computer chips and other integrated circuits.

. . . the new approach enables the production of about 2.5 times as many chips from a single wafer as the 200-mm technology can make.

Multiple Advantages of Wide-Beam Technology

A key innovation in the new technology is passing the wafer under a 350-mm-wide ion beam for implantation, rather than scanning the ion beam across the wafer. The broad beam is very stable and therefore highly accurate. The new equipment incorporating this technology is also significantly simpler than earlier machines and so is cheaper to build and maintain and is more reliable. Use of the DSG technology has already improved fabrication quality substantially relative to the existing industrywide standard. It doubled the mean time between failures, which means that on average, failures occur only half as often as with current equipment.

The DSG technology also lowers fabrication costs by allowing implant equipment to be designed to work on one wafer at a time. Although it seems counter-intuitive, single-

PROJECT:

To develop a novel approach for introducing dopants — substances that alter the electrical properties of semiconductor materials — into large semiconductor wafers to enable faster, less-costly fabrication of larger wafers with smaller, more-densely packed components.

Duration: 3/1/1993 — 6/30/1994

ATP number: 92-01-0115

FUNDING (IN THOUSANDS):

ATP	$1,326	77%
Company	393	23%
Total	$1,719	

ACCOMPLISHMENTS:

DSG developed broad-beam ion-implantation technology (now embodied in Varian's SHC80 Serial High-Current Implanter) that successfully implanted the first commercially viable 300-mm semiconductor wafer. The new technology doubled the existing industrywide mean time between failures and provided additional ways to increase the quality and reduce the cost of chip fabrication. The company:

- received two patents for technology related to the ATP project:

  "Compact High-Current Broad-Beam Ion Implanter"

  (No. 5,350,926: filed 3/11/1993, granted 9/27/1994) and

  "High Speed Movement of Workpieces in Vacuum Processing"

  (No. 5,486,080: filed 6/30/1994, granted 1/23/1996);

- applied for two additional patents for technologies related to the ATP project;
- licensed the technology developed during the ATP project to Varian, which incorporated it in its SHC80 implant system and is actively selling the equipment to commercial customers; and
- licensed its technology to Mitsui Electronics and Shipbuilding for a flat-panel display application, after U.S. companies declined the licensing opportunity. DSG used $6.1 million from Mitsui to develop a 650-mm flat-panel component for displays. In 1997, Mitsui signed its first contract to supply the displays to a customer.

COMMERCIALIZATION STATUS:

The technology has been commercialized in one application and is very near commercialization for a second application. Chip manufacturers using the Varian SHC80 implant system (which incorporates the technology) are producing larger (300-mm) wafers than before (200-mm) and making them faster, with higher quality and at lower cost.

OUTLOOK:

The outlook is excellent. Varian is already selling semiconductor fabrication equipment that incorporates the new technology, and a flat-panel display application is under way. The technology generates cost savings not only for companies using it to make computer chips but also for those who ultimately buy the chips and the products containing them. The benefits directly captured by DSG will likely be only a small fraction of the total net benefits the technology generates for the economy.

COMPANY:

Diamond Semiconductor Group, LLC (DSG)
30 Blackburn Center
Gloucester, MA 01930

Contact: Manny Sieradzki
Phone: (978) 281-4223

Number of employees:
9 at project start, 25 at the end of 1997

Informal collaborator:
Varian Associates Inc.

The new equipment . . . is cheaper to build and maintain and is more reliable.

wafer processing is actually an advantage. Fewer wafers are lost if equipment fails, compared with current technology. The latter involves clamping 13 to 17 wafers to a large wheel, which then rotates at about 1,200 rpm under the ion beam. One failure may result in 13 to 17 unacceptable wafers. With single-wafer processing, only one wafer would be lost. In addition, single-wafer processing enables ion implantation to be coordinated much better with other fabrication steps, most of which are also performed one wafer at a time.

Licensing for Two Different Applications

The ATP project is already a commercial success. DSG licensed the technology to Varian Associates, an ion-implant equipment manufacturer, which has incorporated the new technology into products now being sold.

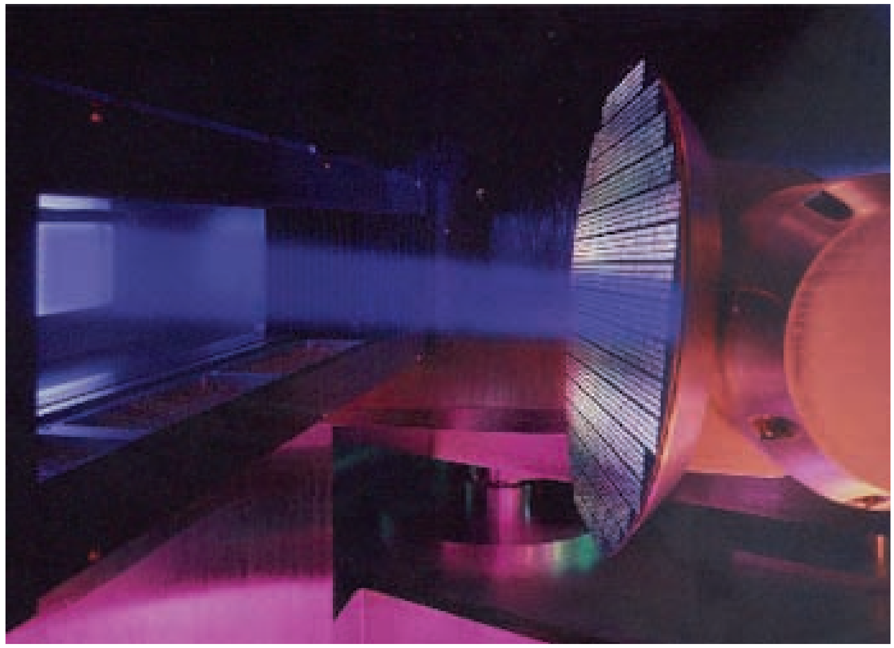
Worldwide sales of ion implanters total $1 billion to $1.2 billion per year, and Varian has 40 percent to 50 percent of the market. Most of the equipment currently sold is for 200-mm wafers, and Varian was the first to market equipment that handles 300-mm wafers. Over the next five years, industry analysts say, the majority of implanters sold will be for 300-mm wafers. All 300-mm-wafer ion implanters currently manufactured by Varian include the DSG technology, and those produced in the future are expected to, as well.

DSG is also developing the technology for another application: flat-panel displays, such as those used in notebook computers. The company has completed the development work through a licensing agreement with Mitsui Electronics and Shipbuilding, which invested $6.1 million in the effort. In late 1997, Mitsui announced it had already won a contract to supply the panels to a customer. Prior to licensing the technology to Mitsui, DSG attempted to interest U.S. flat-panel display companies in it. But most of this industry is off shore, and there were no interested parties in the United States.

Benefits All Along the Supply Chain

DSG's broad-beam technology enables the generation of substantial economic benefits. Varian sells its ion implanters to chip-fabrication companies such as Intel, Motorola and Texas Instruments. These companies, in turn, sell their chips to manufacturers that use computer chips in their products — computer companies like Apple, Gateway, Hewlett-Packard and IBM, as well as firms that make automobiles, appliances, consumer electronics and communications equipment. All along this chain of production, the new technology is saving costs and improving quality.

End users of these products can also expect to benefit from the new technology. Businesses that use desk-top computers containing chips made with this technology, for example, will



The uniform ribbon beam vertically scanning a wafer, in an ion implanter manufactured by Varian Associates.

get lower-cost, higher-quality machines. These will enable better services at lower costs, producing economic benefits for the businesses and their customers. Ultimately, company officials say, the profit DSG earns from its new technology will likely be only 1 percent to 2 percent or less of the total incremental economic benefits the technology is apt to generate across the economy, that is, the spillover benefits are likely to be large.

. . . the company's status as an ATP participant facilitated the agreement it negotiated with Varian . . .

ATP Award Invigorates Small U.S. Company

DSG reports that without the ATP award, it would probably have been unable to do the research or survive as a company. Its only other alternative then was to become part of a foreign company. All the high-risk research and development work on DSG's broad-beam technology was done during the ATP project, and there was a high likelihood of failure. In addition, the company's status as an ATP participant facilitated the agreement it negotiated with Varian to help DSG meet its cost share for the project and, later, to include the technology in Varian's wafer implantation equipment.

FSI International, Inc.

A Gas Method to "Dry" Clean Computer-Chip Wafers

Manufacturing processes create parts for further assembly or final use, as well as a certain amount of waste. Even if waste is severely controlled, the part that emerges from fabrication is almost always contaminated to a greater or lesser degree by unwanted particles. The level of unwanted particles varies with the process, and so does its effect on the rest of production. If the new part is a slice of silicon crystal about to be covered by microscopic integrated circuits, the presence of unwanted particles — even in minute amounts — is disastrous. Extreme cleanliness, therefore, is the rule in silicon chip-making plants, where fabrication takes place in "clean rooms" designed to eliminate contamination.

New Technology to Clean Ever Smaller Chip Features

In computer-chip fabrication, a silicon-crystal wafer is thoroughly cleaned before microscopic electronic components are deposited on it. Conventional cleaning techniques use caustic "wet" chemicals that could be hazardous to workers and that must be discarded after use, generating disposal costs and the potential for environmental pollution if the chemicals are not handled properly. In addition, for chips with feature sizes below a minimum, wet chemicals may not be able to get to some features, such as trenches, because of surface tension.

. . . the presence of unwanted particles — even in minute amounts — is disastrous . . .

Potentially Safer and Less-Costly

The ATP award allowed FSI International, which provides semiconductor wafer surface conditioning equipment and support products, to develop a "dry" cleaning procedure that uses chlorine, chlorine/hydrogen and other gases to clean dirt, trace metals and other particles from wafer surfaces. Researchers completed the assembly and installation of an experimental module and developed required support processes. Although the gases are toxic, they are more easily controlled than wet chemicals. And even though the gases incur disposal costs, the amount of chemical waste generated by the FSI technology is expected to be much smaller than that created via traditional wet cleaning. Thus, the new technology should improve human and environmental safety and reduce cleaning costs during wafer processing.

FSI's methodologies for gas-phase dry cleaning were developed for use in making computer chips and have potential applications in the fabrication of printed circuit boards, disk drives and optoelectronics. If the market emerges and the FSI technology becomes widely used, substantial economic benefits would likely accrue all along the supply chain for computers and other equipment that include chips. The technology is undergoing initial testing at Texas Instruments. If the testing is successful, FSI officials say, Texas Instruments would likely buy and use systems incorporating the new technology.

ATP funding was critical to generating the gas-phase dry cleaning technology, FSI officials report. The company would not have done the research and development work at that time without it. The ATP award also enabled FSI to collaborate with Massachusetts Institute of Technology researchers during the project.

Commercialization Delayed but Still Expected

Since initiation of the ATP project, manufacturers of wafer-surface conditioning equipment have found ways to squeeze more improvements out of wet-chemical cleaning methods. Consequently, chip fabricators have less need for a dry cleaning technique than was initially anticipated. The company expected that the shift in 1997 to smaller (0.25 micron) minimum feature sizes for wafer processing would challenge the capabilities of conventional wet cleaning processes. Wet processing, however, continues to meet cleaning needs at this level and may even be viable to minimum feature sizes of 0.18 micron, which are expected to be introduced in the year 2000. Furthermore,

. . . caustic "wet" chemicals that could be hazardous to workers and that must be discarded after use, generating disposal costs and the potential for environmental pollution . . .

. . . the new technology should improve human and environmental safety and reduce cleaning costs during wafer processing.

progress has been made in reducing the amount of chemicals needed for wet cleaning processes.

Commercialization of the ATP-funded technology, therefore, depends on how much more the wet method can be extended, as well as on the remaining development work needed to demonstrate the robustness, manufacturability and reliability of the process and equipment in a chip-manufacturing environment. Although the new technology has not become a broad replacement for traditional wet cleaning in wafer processing, as originally envisioned by the ATP-project proposal, FSI anticipates the emergence of new applications requiring the unique capabilities of its technology. If the dry cleaning technology is commercialized, chip fabricators that use the new technology might achieve process improvements worth up to five times their costs for the technology, company officials say. FSI has continued to develop this technology while delaying commercialization until demand increases sufficiently. If that happens soon, the company could have a product on the market in 1999.

PROJECT:
To develop a cost-effective process to remove surface contaminants from computer-chip wafers during manufacturing, using dry gases (as opposed to wet chemicals) that can clean the ever smaller features on new generations of chips.

Duration: 3/1/1993 — 2/28/1995
ATP number: 92-01-0022

FUNDING (IN THOUSANDS):

ATP	$2,000	36%
Company	3,482	64%
Total	$5,482	

ACCOMPLISHMENTS:
FSI achieved its R&D goal of developing a dry gas wafer-cleaning method. Evidence of progress is that the company:

- received three patents related to the ATP project:

  "UV-Enhanced Dry Stripping of Silicon Nitride Films"
  (No. 5,534,107: filed 8/18/1994, granted 7/9/1996),

  "Apparatus for Surface Conditioning"
  (No. 5,580,421: filed 12/21/1994, granted 12/3/1996), and

  "Cleaning Method"
  (No. 5,716,495: filed 3/25/1996, granted 2/10/1998);
- applied for nine additional patents, one of which has been unofficially granted (allowed but not yet published);
- presented or published nine technical papers in the area of dry cleaning, etching or stripping of surfaces;
- received a license to complementary technology that could accelerate the commercialization of an advanced dry gas-phase cleaning system;
- entered into an agreement with Texas Instruments for early-stage testing of a prototype; and
- constructed a manufacturing facility to handle all FSI International Surface Conditioning Division manufacturing, including products incorporating the ATP-funded technology.

COMMERCIALIZATION STATUS:
No commercialization has occurred so far, owing to unanticipated changes in demand for the new technology. The shift in 1997 to 0.25-micron minimum feature sizes for wafer processing was expected to challenge the capabilities of conventional wet cleaning processes. Wet processing, however, continues to meet cleaning needs for 0.25-micron features and may even be viable to minimum sizes of 0.18 micron, which are expected to be introduced in the year 2000.

OUTLOOK:
Commercialization prospects are uncertain. Much depends on how the market moves, as well as on remaining development work needed to demonstrate the robustness, manufacturability and reliability of the process and equipment in a chip-manufacturing environment. Although the ATP-funded technology has not replaced traditional wet cleaning in chip processing, as originally envisioned by the ATP-project proposal, FSI anticipates the emergence of new applications requiring the unique capabilities of its technology.

COMPANY:
FSI International, Inc.
322 Lake Hazeltine Drive
Chaska, MN 55318-1096

Contact: Jeff Butterbaugh
Phone: (612) 448-8089

Number of employees:
540 at project start, 1,295 at the end of 1997

Unofficial collaborator: Massachusetts Institute of Technology, Department of Chemical Engineering

FSI has continued to develop this technology while delaying commercialization until demand increases sufficiently.

Galileo Corporation

Low-Cost Night-Vision Technology

Objects around us emit or reflect electromagnetic radiation, some of it in the form of visible light that we can see. None of us sees well when the light is poor, whether at night, in fog or under other circumstances of darkness.

Seeing in the Dark

If a way could be found to magnify the unseen emissions that remain even in darkness, by passing them through special "glasses," then we could "see" things even when the light is too dim to sense objects with the naked eye. Such glasses already exist. They were developed for military use and are quite expensive. High-performance night-vision devices typically cost more than $1,000 — too much for general consumer use.

This ATP project with Galileo Corporation, founded in the middle 1970s to develop microchannel plates (MCPs), aimed to develop a much less-expensive process technology that would make night-vision devices widely available to, for example, law enforcement officials and the estimated 400,000 Americans suffering from retinitis pigmentosa (night blindness). Another potential use of the technology is in detector components for highly miniaturized analytical instruments. Funding from the ATP enabled Galileo to perform research to develop the new fabrication processes and higher performance prototype MCPs that it would otherwise have been unable to do and helped the company form alliances with research partners and contractors.

. . . a much less expensive process to make devices widely available to law enforcement officials and the estimated 400,000 Americans suffering from retinitis pigmentosa . . .

New Electron Multipliers

The ATP project involved the development of new kinds of electron multiplier devices based on the same kind of manufacturing technology used in semiconductor fabrication. An MCP is a flat, usually disc-shaped array of closely packed microscopic tubes that act as tiny amplifiers. Electrons, photons or ions entering one side of the plate trigger a cascade of thousands of electrons out the other side. MCPs form the heart of image intensifiers used in night-vision and scientific devices and electronic imaging systems. MCPs are currently made using glass-working techniques developed for producing fiberoptic bundles. The process has been improved greatly over the years but has reached its limits in terms of further cost reductions and performance improvements.

Galileo's ATP project abandoned the glass-fiberoptic production approach to MCPs and instead used the photolithography, dry-etch, wet-etch, and thin-film-deposition technologies developed by the semiconductor industry to develop improved MCPs. The company succeeded in the technical goals of the project, developing new fabrication procedures and using them to demonstrate prototypes of working, high performance electron-multiplier devices.

Financial Distress

During the last six months of its 26-month ATP project, Galileo encountered financial problems and decided to abandon its original goal of in-house commercialization of the new process technologies for electron multipliers. The company has continued to produce MCPs using its earlier fabrication process and sell them. Even though feasibility of the new approach was demonstrated by the ATP project, Galileo officials reported that another $5 million investment would have been needed to commercialize the advanced performance MCPs using the new process. They say they could not justify the investment for commercialization, given the company's financial difficulties and the length of time needed to build revenue streams.

Commercialization Potential

At the close of the project, the company entered into an agreement with the Center for Advanced Fiberoptic Applications (CAFA), a new nonprofit consortium charged with commercializing technologies developed by Galileo and other CAFA members, mainly small to

During the last six months of its 26 month ATP project, Galileo encountered dire financial problems and decided to abandon its original goal of in-house commercialization . . .

Galileo granted a non-exclusive royalty-free license of the ATP-funded technology to CAFA.

medium sized optics companies in the mid-Massachusetts area. Galileo granted a non-exclusive royalty-free license of the ATP-funded technology to CAFA. The principal investigator on the ATP project left Galileo to become section head for microelectromechanical systems in the CAFA consortium. In addition to licensing agreements, CAFA is pursuing partnerships with a number of companies as an avenue for commercializing the ATP-funded MCP technology, but the chances for commercialization are uncertain at this time.

In theory, it is expected that the technology will reduce the costs of MCP production and improve performance, but these effects have not yet been shown in practice. The prototype demonstration focused on the feasibility of the new process technology adapted from the semiconductor industry to produce MCPs and on improved MCP performance, rather than on their comparative costs. Laboratory tests and calculations suggested that production costs would be lower using the new technology, but no pilot project has yet been developed, so those predictions have not been confirmed. Demonstrated lower costs and improved performance would make it more feasible to pursue new market opportunities for applications to address night blindness.

. . . CAFA is pursuing partnerships with a number of companies as an avenue for commercializing . . .

PROJECT:
To develop fundamentally new, lower-cost fabrication processes for and prototypes of higher quality microchannel plates (MCPs) — which form the heart of image intensifiers used in night vision — to enable wider use of the technology, including applications for the estimated 400,000 Americans suffering from retinitis pigmentosa (night blindness).

Duration: 4/1/1993 — 5/31/1995
ATP number: 92-01-0124

FUNDING (IN THOUSANDS):

ATP	$1,910	57%
Company	1,428	43%
Total	$3,338	

ACCOMPLISHMENTS:
Galileo developed new processes for fabricating MCPs and other types of electron multipliers, using techniques from semiconductor fabrication, and used the new processes to produce prototype MCPs. As evidence of these accomplishments, the company:

- received four patents for ATP-related technology:

  "Method for Fabrication of Discrete Dynode Electron Multipliers"
  (No. 5,618,217: filed 7/25/1995, granted 4/8/1997),

  "Method for Fabrication of Microchannel Electron Multipliers"
  (No. 5,569,355: filed 1/11/1995, granted 10/29/1996),

  "Microfabricated Electron Multipliers"
  (No. 5,568,013: Filed 7/29/1994, granted 10/22/1996) and

  "Fabrication of a Microchannel Plate From a Perforated Silicon Workpiece"
  (No. 5,544,772: filed 7/25/1995, granted 8/13/1996);

- published five technical papers, including one as a dissertation and four in professional journals;
- produced working vacuum-electron multipliers by microfabrication methods; and
- developed thin-film techniques to produce dynode structures that support electron multiplication in MCPs and other channel electron multiplier devices.

COMMERCIALIZATION STATUS:
No products based on the ATP-funded technology have yet reached market.

OUTLOOK:
Prospects for commercialization of this technology are uncertain. Financial difficulties forced Galileo to abandon plans to directly commercialize the ATP technology. The company now is working with the Center for Advanced Fiberoptic Applications (CAFA), a nonprofit consortium charged with commercializing technologies developed by Galileo and other CAFA members. If CAFA can commercialize the ATP technology to benefit people suffering from night blindness, or if the technology is adopted for use in producing miniature scientific and analytical instruments, such as a mass spectrometer on a chip, the broad economic benefits could be very large.

COMPANY:
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Enrique Bernal G.
Galileo Corporation
(508) 347-4291

William Tasker
Center for Advanced Fiberoptic Applications
(508) 765-0180

Number of employees:
314 at project start; 240 at the end of 1997

In addition, the technology holds further potential that might one day be realized. It is important for miniature scientific and analytical instruments — for example, a mass spectrometer on a chip. The National Aeronautics and Space Administration (NASA) recently awarded a contract to develop components for miniaturized mass spectrometers to CAFA, Galileo and the Argonne National Laboratory, under which prototypes have been delivered and are now being evaluated. While the NASA contract did not itself involve the use of the ATP-funded technology, extensions to additional contracts could easily do so, because of the need for additional miniaturization. Commercialization of the technology for this application, if it can be accomplished, could also have far-reaching economic benefits.

Hampshire Instruments, Inc. (Joint Venture)

Large-Scale Diode-Array Laser Technology for X-Ray Lithography

Today's stamp-size computer chips are made by lithography systems that project ultraviolet (UV) or deep-UV light through stencil-like masks onto silicon wafers to produce the tiny components of integrated circuits (ICs), or chips. To make higher-performing ICs, more transistors and denser circuitry will have to be packed onto each chip.

Ever Smaller, Denser Computer Chips

Today's densest chips have feature sizes of about 0.15 mm, which can barely be produced with deep-UV lithography. To make even smaller chips, the next generation of lithography equipment may use x-rays, which have shorter wavelengths than visible or UV light. Shorter wavelengths are needed to make tinier features.

An Inexpensive Laser Approach

X-ray lithography able to make chip features of 0.10 mm and smaller was demonstrated prior to the start of this project in 1991. But cost-effective x-ray lithography systems capable of large-scale IC manufacturing were not available. Research had shown that a relatively inexpensive device using a high-energy laser to stimulate x-ray emission could be used to produce x-rays. Suitable material (neodymium-doped gadolinium gallium garnet, or Nd:GGG) for this type of laser was available. However, the inability to precisely control the energy used to pump up the material's energy level was a key problem in making such a laser work.

This ATP joint venture project by Hampshire Instruments and McDonnell Douglas Corporation (MDC), with help from Lawrence Livermore National Laboratory, solved the control problem by developing methods for using powerful arrays of laser diodes to pump Nd:GGG in a laser-based x-ray lithography system. Hampshire, a small New York company, contributed its laser design expertise. MDC provided expertise in system design and the design of the critical high-power laser-diode pump. It also provided the world's largest laser-diode-module manufacturing capacity to support post-project commercialization goals.

Prior to the ATP-funded work, MDC built a prototype laser-diode-pump system with a peak power output of more than 300 kW. The system was successfully used to pump a Hampshire laser being developed for a second-generation x-ray lithography system, and its pumping was significantly more efficient than that of the flash lamps Hampshire had used in its first-generation x-ray lithography system. In addition, life testing of laser-diode-pump systems showed they lasted much longer than the longest-lasting flash lamps then available.

Soon after the ATP project was completed, Hampshire ran into serious financial problems, declared bankruptcy and was liquidated.

Doubling the Peak Power Output

During the ATP project, MDC built two prototype laser-diode-pump systems that each delivered more than 750 kW of peak power, by far the highest laser-diode power produced by any device then or now. Both met or exceeded all performance and reliability specifications. MDC kept one pump and delivered the other to Lawrence Livermore for testing in the second-generation x-ray lithography system being developed by the lab and Hampshire. The pump, however, was never integrated with the Hampshire laser. Flash lamps with longer life became available, leading Lawrence Livermore to shift its focus to flash-lamp pumping of the laser. The lab continues to develop x-ray lithography.

High Expectations Dashed by Bankruptcy

Evidence at the start of the project suggested the ATP-funded technology would be rapidly commercialized if it could be successfully developed and demonstrated. Hampshire and MDC planned to sell the new x-ray lithography system in a worldwide market expected, when the proposal was written, to exceed $1.5 billion by 1994. They also hoped to sell the technology in solid-state laser markets.

Hampshire, however, ran into serious financial problems and failed to raise the addi-

. . . MDC built two prototype laser-diode-pump systems that each delivered more than 750 kW of peak power, by far the highest laser-diode power produced by any device . . .

PROJECT:

To develop a laser-diode-pumped laser system for generating x-rays in a new generation of lithography equipment to enable a major advance in the miniaturization of computer chips while reducing manufacturing costs.

Duration: 7/1/1991 — 9/30/1992
ATP number: 90-01-0126

FUNDING (IN THOUSANDS):

ATP	$926	50%
Company	930	50%
Total	$1,856	

ACCOMPLISHMENTS:

Researchers demonstrated the feasibility of using a powerful laser-diode-array to pump up the energy level of Nd:GGG (neodymium-doped gadolinium gallium garnet) in a laser intended for use in producing x-rays. Such a laser could be scaled up to meet the technical, reliability and affordability requirements for third-generation x-ray lithography systems. All planned tasks were accomplished. The company presented some results at the Advanced Solid State Laser Conference in 1992.

COMMERCIALIZATION STATUS:

No attempt to commercialize the technology has occurred. Soon after the ATP project was completed, Hampshire ran into serious financial problems, declared bankruptcy and was liquidated. The company's demise halted the effort to develop this type of laser-based x-ray lithography and led to the collapse of MDC's laser-diode business.

OUTLOOK:

The New York Job Development Authority — which now owns practically all Hampshire assets, including intellectual property — shows no intention to commercialize the technology. Neither does MDC (Boeing). The semiconductor industry has shifted some of its attention from x-ray lithography to competing technologies such as deep ultraviolet (DUV) lithography utilizing excimer lasers. However, given the expectation that feature resolution limits of DUV lithography will be reached in a few years, x-ray lithography continues to arouse interest. If the industry comes to view the x-ray approach as a viable candidate for a new generation of lithography equipment, the technology developed in this ATP project could be revisited.

COMPANIES:

Hampshire Instruments, Inc.
(joint venture lead)
(Since April 25, 1993, no longer in business)

Other joint venture participant:

McDonnell Douglas Corporation (MDC),
now merged with The Boeing Company

5000 E. McDowell Road
Mesa, AZ 85215-9797

Contact: Henry B. Morris
Phone: (602) 891-2194

Informal collaborator:
Lawrence Livermore National Laboratory

tional funds needed to survive. The company declared bankruptcy and was liquidated. The New York Job Development Authority assumed ownership of practically all Hampshire assets, including its intellectual property. For a time, several organizations expressed interest in acquiring the technology, but none completed the acquisition. MDC intended to commercialize its laser-diode pumps for a variety of applications. With Hampshire's demise, that plan did not materialize. There is currently no effort to commercialize the ATP-funded technology, either by Boeing (MDC) or government agencies. But this may change with renewed interest in x-ray lithography in the future.

Illinois Superconductor Corporation (ISC)

Using High-Temperature Superconductivity to Improve Cellular Phone Transmission

The number of cellular phones used in the United States has mushroomed in the last decade. Estimates provided by the Cellular Telecommunications Industry Association are that the number of wireless telephone subscribers was over 50 million as of August 1997. Additional estimates are that by 2001 the cellular subscriber base is expected to grow to more than 75 million subscribers, with an additional 15.1 million subscribers using personal communications services (PCS) by the same year.

Extending and Improving Cellular Phone Service

To provide cellular phone or PCS service, a communications company using a land-based approach must place base stations — towers and reception/transmission equipment — at regular intervals throughout its service area. In deciding where to locate these base stations, the company considers the strength and clarity of its communications signals and how customer service will be affected when a signal shifts from one station to the next while the customer is traveling.

All these factors depend on how well the station's equipment handles the communications signals. And that depends on how well each component of the equipment works as it attempts to distinguish the user's cellular phone signal from the surrounding electronic noise.

A compact one-box enclosure for *RangeMaster*® and *SpectrumMaster*®

A High-Temperature Superconductivity Solution

This ATP project with Illinois Superconductor Corporation (ISC), a small company founded in 1990, developed technology based on high-temperature superconductivity (a phenomenon discovered in 1986) to significantly improve the quality of signal transmission.

Superconducting components offer great benefits to cellular phone communications, including improvements in range, receiver sensitivity and frequency stability. These improvements, in turn, will extend the range of base stations, reducing the number needed to cover a given area and decreasing the costs of cellular phone service. Cellular phone users will receive clearer signals and suffer fewer dropped calls as their signals move from one base station site to the next.

Cellular phone users will receive clearer signals and suffer fewer dropped calls as their signals move from one base station site to the next.

Despite the promise of superconducting components, little prior work had gone into developing HTS components for the radio-frequency (RF) spectrum, which is used by cellular phone systems. Difficulties in economically making the relatively large, geometrically complex structures needed for these frequencies were partly to blame. ISC solved this problem by developing the ability to use thick-film HTS coatings on inexpensive substrates.

Focus on Preselector Receive Filters

The goal of the ATP project was to develop and demonstrate consistently performing RF superconducting components in a prototype base station. During the ATP project, however, ISC narrowed its focus (with ATP approval) to preselector receive filters, which remove all extraneous RF signals and leave only those within the cellular spectrum allotted to that

. . . received the *Microwave & RF* magazine 1996 Top Product Award for "cellular phone site filters, superconducting ceramics" . . .

A ceramic torroid form, coated with thick film HTS material, designed to resonate at a specific frequency.

By September 1997, ISC had installed SpectrumMaster™ or RangeMaster™ in 22 base stations in 12 cities and had successfully completed 16 field trials in 10 cities.

PROJECT:

To develop high-temperature, superconducting thick-film materials for equipment used in the reception/transmission stations of cellular phone and other communications systems.

Duration: 3/1/1993 — 2/29/1996
ATP number: 92-01-0017

FUNDING (IN THOUSANDS):

ATP	$1,980	56%
Company	1,555	44%
Total	$3,535	

ACCOMPLISHMENTS:

ISC developed and demonstrated a robust fabrication process to produce radio-frequency (RF) components using thick-film, high-temperature superconductivity (HTS) technology. It developed a model that predicts the impact of high-performance filters on future digital wireless systems. The company also:

- received five patents for technologies related to the ATP project:

  "Superconducting YBa.sub.2 Cu.sub.3 O.sub.7-x Produced at Low Temperatures"

  (No. 5,527,765: filed 8/23/1994, granted 6/18/1996),

  "Electromagnetic Resonant Filter Comprising Cylindrically Curved Split Ring Resonators"

  (No. 5,616,540: filed 12/2/1994, granted 4/1/1997),

  "Electromagnetic Resonator Comprised of Annular Resonant Bodies Disposed Between Confinement Plates"

  (No. 5,629,266: filed 12/2/1994, granted 5/13/1997),

  "Resonator Mounting Mechanism"

  (No. 5,604,472: filed 12/1/1995, granted 2/18/1997), and

  "Superconducting Re-entrant Resonator"

  (No. 5,682,128: filed 4/23/1996, granted 10/28/1997);

- applied for one additional patent for technology related to the ATP project;
- raised $17.4 million through an initial public stock offering in October 1993;
- completed construction of a plant to manufacture RF filters and related products;
- began selling SpectrumMaster® in 1996 and RangeMaster™ in 1997, both of which are based on the ATP-funded technology;
- received the *Microwave & RF* magazine 1996 Top Product Award for "cellular phone site filters, superconducting ceramics," which were selected from a field of 5,000 new products; and
- received (with subcontractor Lucent Technologies) a Corporate Technical Achievement Award for 1997 from the American Ceramic Society.

COMMERCIALIZATION STATUS:

Commercialization is in progress and products are being sold. The benefits of lower costs and higher-quality service are accruing to companies that use ISC's new technology and to their customers.

OUTLOOK:

The outlook for this new technology is excellent. Its use is expected to spread throughout the economy, lowering the costs and improving the quality of cellular phone and personal communication services.

COMPANY:

Illinois Superconductor Corporation (ISC)
451 Kingston Court
Mt. Prospect, IL 60056

Contact: Ben Golant
Phone: (847) 391-9416

Number of employees:
8 at project start, 75 at the end of 1997

particular operator. Investigation of the cellular market indicated that the superconducting preselector receive filter was of greatest interest to customers in terms of improving system performance. Given the limited resources available to ISC, the company decided to focus on this component as an initial goal and to integrate others later. The new HTS technology is useful for other RF equipment and has potential applications in antennas, magnetic resonance imaging machines and other components of communications systems.

ISC successfully incorporated the ATP-funded technology in a preselector receive filter and, in late 1996, started selling it under the name of SpectrumMaster® to companies operating cellular phone systems. A year later, it launched RangeMaster®, which contains the SpectrumMaster® preselector receive filter and a cryogenically cooled low-noise amplifier. By September 1997, ISC had installed SpectrumMaster® or RangeMaster® in 22 base stations in 12 cities and had successfully completed 16 field trials in 10 cities. Sales at that time amounted to $1 million. The company has also modified and installed SpectrumMaster® for use in the base stations of personal communications systems.

Improved Communications Service

The future looks bright for ISC as it uses the ATP-funded technology to help communications companies serve their customers with greater-quality services at lower costs. Cellular phone service companies can reduce the number of new base station sites they install. They can also expand by up to 25 percent the range of existing sites by replacing an older filter at the station with a new one based on the ATP-funded technology. A 25 percent range increase corresponds to a 56 percent increase in the area covered and translates into a 40 percent decrease in the number of sites required to cover the area. The cost of the improved filter is around $25,000 to $60,000, depending on site configuration, whereas the cost of a new site is about $1 million to $2 million.

The future also looks bright for customers of these communications companies, as costs drop and service quality improves.

Even greater benefits should accrue to cellular and personal communications customers with the conversion from analog to digital communications. Digital stations must transmit much more data per call, so any quality improvements or cost reductions will apply to a larger volume of signal traffic. As more transmission sites install digital systems, cellular phone users will get clearer signals and fewer dropped calls. Other sectors, such as mobile communications, will experience lower costs and improved quality as the technology is extended to them. Proliferation of the new technology will provide an additional benefit in terms of aesthetics by reducing the number of signal towers installed for communications systems.

ATP Award Accelerates Development

Funding from the ATP enabled ISC to form alliances with research partners and contractors and to achieve its research and development results about 18 months earlier than it would otherwise have been able to do. Company officials say the ATP award also enabled ISC to survive as a company and gave its technology and commercialization plan significant credibility with investors. The increased credibility, in turn, directly helped the company raise private capital, especially during its initial public stock offering in 1993.

A 25 percent range increase corresponds to a 56 percent increase in the area covered and translates into a 40 percent decrease in the number of sites required to cover the area.

Light Age, Inc.

Exploiting Alexandrite's Unique Properties for a Less-Expensive, More-Reliable Tunable Laser

Lasers today drive many devices throughout the consumer and commercial worlds. There are tiny ones in printers and CD-ROM players, small ones in medical instruments and large ones in satellite communications systems. Besides coming in different sizes, lasers vary in the wavelength and strength of the light they produce. In almost all applications, the wavelength and power of the beam are fixed.

Tunable Lasers for Many Uses

This ATP project with Light Age, a small privately held company, developed a convenient, reliable, tunable, compact laser source of ultraviolet (UV) light suitable for spectroscopy, medical applications, photochemical research, electronics fabrication, and laboratory studies of atomic and molecular science. Of particular importance, the new laser can be tuned to the shorter UV wavelengths known as vacuum UV (VUV) light.

The new device is the brightest (most powerful) available tunable source of laser light over much of the UV spectrum.

Light Age was founded in 1985 by two scientists who, at AlliedSignal, had pioneered and managed the development of a tunable-wavelength laser based on the alexandrite crystal. The new light source developed in the ATP project offered improvements over the AlliedSignal technology and is less expensive, operationally simpler and more reliable than other tunable laser light sources. It uses the fundamental output of the alexandrite laser, which is broadly tunable between 700 and 800 nanometers (nm). That output is then converted to UV wavelengths of 190-200 nm, 240-270 nm or 350-400 nm. The new device is the brightest (most powerful) available tunable source of laser light over much of the UV spectrum.

Surgery and Photolithography

The new tunable laser is particularly promising for corneal sculpting and angioplasty because it provides the control needed for these advanced applications. Its advantage stems from the fact that laser beams of certain wavelengths affect some tissue types but not others. The laser can be tuned, for example, to the wavelength of a light beam that destroys diseased tissue while leaving healthy tissue undamaged.

The laser can be tuned, for example, to the wavelength of a light beam that destroys diseased tissue while leaving healthy tissue undamaged.

Another, quite different potential application is in photolithography equipment for the production of faster, higher-density, next-generation computer chips. Shorter-wavelength light is needed to produce the finer features on these chips. And reliable lasers that can generate shorter-wavelength light are needed to move beyond this manufacturing choke point. As recently as 1995, almost all chip photolithography used light in the near-UV range (around 350 nm) produced by UV light bulbs. Today, the industry is rapidly moving toward

The *Pal/Pro - UV*™ laser system, tunable to 248 nanometers, 193 nanometers, and other ultraviolet wavelengths.

PROJECT:
To develop a safe, compact, convenient, reliable, less-expensive, broadly tunable laser source of ultraviolet (UV) light — particularly at shorter UV wavelengths — suitable for use in science, medicine and photolithography.

Duration: 4/1/1991 — 9/30/1993
ATP number: 90-01-0212

FUNDING (IN THOUSANDS):

ATP	$702	41%
Company	1,010	59%
Total	$1,712	

ACCOMPLISHMENTS:
Light Age accomplished its R&D goal. The company also:

- introduced several new or improved laser products incorporating the ATP technology, including:
  - nUVo™ — a continuous-wave, diode-pumped, solid-state laser producing UV light,
  - PAL/UV™ — a solid-state laser source of 193-nanometer light, and
  - PAL/PRO™ — a narrow spectral bandwidth version of the PAL™ laser;
- increased revenues an average of 50 percent per year since the end of the ATP project in 1993, with 1997 revenues exceeding $2.8 million on sales of lasers incorporating the new technology; and
- received more than $10 million worth of product orders, which are currently being filled.

COMMERCIALIZATION STATUS:
Light Age lasers incorporating the ATP-funded tunable-laser technology are being sold and put to use in academic R&D and in clinics, hospitals and doctors' offices around the world.

OUTLOOK:
Prospects for wider use of this technology are promising, particularly in medicine for corneal sculpting and angioplasty. Products based on the ATP-funded technology may generate large payoffs to the U.S. economy in science, health care and electronics manufacturing. The company's lasers are also being used in studies to refine and extend global weather prediction methods. If atmospheric research using the new lasers leads to improved weather forecasts, the benefits in this area alone could be huge for businesses and individuals worldwide.

COMPANY:
Light Age, Inc.
2 Riverview Drive
Somerset, NJ 08873

Contact: Donald F. Heller
Phone: (732) 563-0600

Number of employees:
10 at project start, 28 at the end of 1997

deep-UV laser sources that produce light at 248 nm. Future generations of computer chips may require VUV laser sources that produce light at wavelengths of about 193 nm or even shorter.

Large Benefits to Intermediate Users and Customers

Light Age makes UV and VUV lasers costing $20,000 to $200,000. They are used in applications such as health care and scientific equipment that may generate big payoffs to the economy as a whole. In most of these markets, the company's technology faces global competition. Nonetheless, Light Age is already a significant exporter of laser systems for scientific and medical applications and expects strong, continued growth of these exports.

Light Age is already a significant exporter of laser systems . . .

Economic benefits are accruing to intermediate customers and end users of the new technology in medical applications. Many applications of the new laser technology are in environments such as medicine and weather forecasting, where the economic benefits to others besides Light Age are likely to be large.

Potential for Improved Weather Prediction

The company's lasers are being used in institutional and government research on the upper atmosphere to refine and extend global weather prediction methods. In these applications, lasers are a required technology. The research uses UV lidar (light detecting and ranging) to illuminate particular atoms in the mesosphere — about 70 miles above the earth. Specific effects of the illumination are viewed with powerful telescopes, recorded and used to determine the temperature of the environment at that altitude.

This research aims to develop methods for measuring the temperature and wind speed at very high altitudes. Current measurement systems mainly use only ground-level data. Researchers believe that data on several atmospheric strata measured at selected points around the earth could significantly improve the quality of the very large weather prediction computer models now in use. If research using the tunable laser does lead to better weather predictions, the benefits would likely be huge for businesses and individuals not just in the United States, but around the world.

The tunability of the alexandrite laser from Light Age has made this new research feasible. To show their effects, different types of atoms must each be illuminated by a lidar laser of a specific wavelength. With the Light Age laser, that wavelength can be set by a technician using conventional controls. Alternative laser sources for this research are hand-constructed for just one wave-length, which limits their use and makes them much more expensive than the mass-produced Light Age lasers.

Greater Sales and Revenues

Light Age has done well commercially. The company has expanded product offerings and increased sales each year since beginning the ATP project in 1991. The new technology helped Light Age boost revenues an average of more than 50 percent per year after completing the project in 1993. In 1997, the company generated more than $2.8 million in revenues and, at the beginning of 1998, had back orders worth more than four times its 1997 sales.

If atmospheric research using the new lasers leads to improved weather forecasts, the benefits in this area alone could be huge for businesses and individuals worldwide.

Light Age sees itself as an up-by-your-own-bootstraps company in terms of finances. A large part of its success comes from paying detailed attention to financial management, tightening its budgetary belt, retrenching temporarily when needed, pushing new technology-driven products through to market and staying in product areas where its strengths lie. The company has adopted a stringent approach to financial matters, plowing all earnings back into additional research. ATP's participation compelled Light Age to adopt rigorous financial discipline during the company's early development in order to meet the ATP requirement for cost sharing. The belt-tightening was difficult for Light Age in the short run, company officials say, but served the long-term interests of the company.

The ATP funds enabled Light Age to double its research budget during the funding period, a move that allowed the research and development work to be completed 12 to 36 months sooner than it would have been without the award. In addition, company officials say, the visibility generated by winning the ATP award helped Light Age establish agreements with research partners and, coupled with the success of the ATP project, enabled it to secure additional funding from private investors.

Lucent Technologies Inc. (formerly AT&T)

Precision Mirrors for Advanced Lithography

The personal computer revolution has been powered, in large part, by the development and production of new generations of memory, CPU (central processing unit) and other chips. With each generation, chip feature sizes shrink. However, chip feature size is reaching the limit of what can be produced with current lithography equipment. A new approach to lithography that can operate at shorter wavelengths is essential if the integrated circuit industry is to continue to advance toward more powerful computer chips.

Advanced Optics to Enable Chip Miniaturization

The ATP project with Lucent Technologies (formerly AT&T) Bell Laboratories significantly improved the accuracy of precision reflective optics — complex multilayer-coated mirrors — that are critical for extreme ultraviolet (EUV) lithography. EUV, or soft x-ray, technology is one of several possible approaches to advanced lithography for manufacturing chips.

The goal of the project was to discover whether it is possible to create ultrahigh-precision aspherical mirrors that properly reflect EUV wavelengths for use in lithography. This was a high-risk, technically challenging project. ATP cost sharing enabled Lucent to move ahead with a project that otherwise would have been difficult to justify, particularly because so much of the funding would go to collaborators outside the company. Ultimately, the ATP project showed that the technical obstacles were surmountable and that the optics can be manufactured, measured and aligned.

A new approach to lithography that can operate at shorter wavelengths is essential if the integrated circuit industry is to continue to advance toward more powerful computer chips.

Characterizing the complex shapes of these mirror surfaces with the high level of precision required for EUV lithography was well beyond the state of the art when the ATP project began. Working with Lucent, Tropel developed a specialized interferometer to measure aspheric surface characteristics, a device that it now uses in other applications. Lucent, in collaboration with Brookhaven and Sandia National Laboratories and the University of Wisconsin, developed other techniques required to characterize aspheric mirrors. The project also generated increased understanding of multilayer-coated aspherical optics and optics surface finishing, advanced techniques for multilayer coating of mirrors, improved methods for mirror alignment, and new test equipment.

To see whether this new technology would work, Lucent and its collaborators conducted a two-stage, round-robin test. In the first stage, four subcontractors fabricated prototype mirrors using the knowledge created in the project. Then each subcontractor tested mirrors fabricated by each of the four. The mirrors made by Tinsley Laboratories proved to be dramatically better than any of this type ever seen before.

Commercialization Status

When this project began, it was uncertain whether aspheric mirrors with the high level of accuracy required for EUV lithography could be made. And even if they could, it was not clear whether they could be measured with sufficient accuracy to verify that they met the extreme precision demanded by the specifications. Thus, this high-risk project aimed to find out whether the EUV approach to lithography deserved further consideration or whether the mirrors constituted a "show stopper" technical barrier that could not be surmounted. The project demonstrated that the mirror technical barrier could, indeed, be overcome.

Progress on all the advanced-lithography candidate technologies developed in parallel at industry and government laboratories during the early 1990s. As data accumulated, Lucent decided in 1995-1996 (well after the ATP project ended) to reduce its effort in EUV lithography and focus its attention on another option — scattering with angular limitation projection electron-beam lithography (SCALPEL) —

. . . this high-risk project aimed to find out whether . . . the mirrors constituted a "show stopper" technical barrier that could not be surmounted.

The high-quality Tinsley mirrors, fabricated and tested with methods discovered during the ATP project, are a key component of the EUV approach to new generations of lithography equipment.

which it deemed more promising. Lucent still monitors developments in all areas of advanced lithography, and substantial work on EUV lithography continues elsewhere, particularly at Lawrence Livermore and Sandia National Laboratories.

In 1996 Intel, AMD and Motorola formed the Extreme Ultraviolet Limited Liability Company to pursue EUV lithography. In September 1997, this consortium and the Virtual National Laboratory (a collaboration of Lawrence Berkeley, Lawrence Livermore and Sandia National Laboratories) agreed to collaborate on the development of EUV lithography. EUV systems would draw on the optics work from the ATP project and related technology developed at the national laboratories. The three chip makers intend to invest about $250 million over three years in the collaboration to determine whether the technology is commercially viable and, if it is, to pursue commercialization via lithography equipment manufacturers.

It is too early to tell whether the EUV or one of the other approaches to lithography will ultimately win in the marketplace. But it is clear that the ATP project has helped the industry understand the technical barriers to one major candidate technology and how to overcome them. The ATP project results are

PROJECT:
To develop new fabrication, testing and alignment techniques for making extremely precise aspheric (nonspherical curvature) mirrors to use for lithography in the extreme ultraviolet (EUV) portion of the spectrum. This is one of several approaches being considered for fabricating future generations of computer chips with extremely dense, compact microelectronic circuits.

Duration: 5/15/1991 — 5/14/1994
ATP number: 90-01-0121

FUNDING (IN THOUSANDS):

ATP	$2,000	36%
Company	3,525	64%
Total	$5,525	

ACCOMPLISHMENTS:
Lucent and its subcontractors developed dramatically improved techniques for fabricating, testing and aligning extremely precise aspherical, multilayer-coated mirrors essential to EUV technology, a candidate for future lithography systems. Lithography is a key step in manufacturing integrated circuits. Aspheric mirrors, whose surfaces have nonspherical curvature, are much more difficult to make and measure than mirrors with flat or spherically curved surfaces. They are particularly difficult to make for the ultrashort wavelengths used in this technology. Researchers significantly advanced the state of the art of the physics and metrology for these EUV lithography systems. Signs of the project's success are:

- Lucent contracted with Tropel to develop a new advanced interferometer for measuring the surface properties of aspheric optics. Tropel succeeded and is now using this technology for its own products.
- Tinsley Laboratories, a subcontractor, fabricated mirrors 10 times more precise than any produced before the ATP project. Tinsley has applied the improved methods learned in the project to all its products. In part, because of its improved manufacturing technology, Tinsley doubled its sales between 1991 (the start of the ATP project) and 1996.
- The researchers presented or published more than two dozen papers about precision metrology, aspheric mirror fabrication and lithography systems development.
- Three computer chip fabrication companies have agreed to invest $250 million over three years to continue the research, development and perhaps ultimate commercialization of EUV lithography technology. A critical component of this technology is the multilayer-coated mirrors that were the focus of this ATP project.

COMMERCIALIZATION STATUS:
Although Lucent has decided to concentrate on another advanced-lithography approach that appears more promising at this time to the company, some technologies developed during the ATP project have already been commercialized, and others may be commercialized in the future. Tinsley's business rose sharply as a result of manufacturing improvements the firm developed to fabricate the aspheric mirrors for this project. Tropel is using the measurement technology resulting from its involvement in the project. And several computer chip manufacturers are incorporating the project results into their lithography R&D. If the EUV approach meets the technical and economic requirements of the chip industry, the ATP-funded technology will be incorporated into equipment used to produce computer chips in the first decade of the twenty-first century.

OUTLOOK:
The high-quality Tinsley mirrors, fabricated and tested with methods discovered during the ATP project, are a key component of the EUV approach to new generations of lithography equipment. If this approach proves to be technically and commercially viable, it will enable a new generation of chip-making equipment that will generate benefits for chip manufacturers, as well as users of computers, communications equipment and other electronic devices containing the new chips.

COMPANY:
Lucent Technologies Inc., Bell Laboratories
(formerly AT&T Bell Laboratories)
Room 3C-428
600 Mountain Ave.
Murray Hill, NJ 07974

Contact: Richard P. Muldoon
Phone: (908) 582-5330

Subcontractors: Itek Optical Systems, SVG Lithography, Tinsley Laboratories and Tropel Corp.

Informal collaborators: Sandia, Brookhaven and Lawrence Livermore national laboratories and NIST.

The researchers presented or published more than two dozen papers about precision metrology, aspheric mirror fabrication and lithography systems development.

important to this effort because the kind of aspheric mirrors that Tinsley learned to make under contract to Lucent will be a critical component of the EUV lithography equipment.

ATP-Project Benefits Could Be Huge

Benefits have already started accruing to Tinsley, which produced the best aspheric mirrors, and to its customers who use the mirrors. Tinsley attributes much of its recent success to the ATP project, because the company was able to apply the improved manufacturing processes — developed to supply aspheric optics for the project — to all its products. Tinsley's sales have approximately doubled since the ATP project. Furthermore, in just 27 months the value of Tinsley's stock increased 600 percent, indicating the value the market places on the company's enhanced capabilities. Tropel and its customers are also continuing to reap benefits from the interferometer.

If EUV lithography equipment incorporating the new aspheric mirror technology becomes the technology of choice for the next generation of chip-making equipment, the benefits of the ATP project would be far broader. The new technology would have a huge economic impact on the semiconductor industry and generate spillover benefits to companies that use the improved computer chips in a wide variety of products, as well as to consumers who use these products. Even if another lithography approach becomes the technology of choice, benefits to companies like Tinsley and Tropel and to their customers will continue to accrue.

This project illustrates the important fact that a lack of immediate commercialization after an ATP project ends does not mean that the new technology will not eventually be commercialized and yield large benefits.

Information gathered in this project helped Lucent better understand the technical issues related to EUV lithography. Publication of numerous technical papers resulting from the project has advanced the state of the art for everyone in this technical community. And although Lucent later decided to pursue an alternative lithography approach, other companies have incorporated the ATP-funded technology into research and development work that could lead to systems that are commercialized in the future.

. . . in just 27 months the value of Tinsley's stock increased 600 percent, indicating the value the market places on the company's enhanced capabilities.

Multi-Film Venture (Joint Venture, formerly The American Scaled-Electronics Corporation)

Joining Several Chips Into One Complex Integrated Circuit

In the race to boost the performance and decrease the size of the integrated circuits (ICs) used in computers, one limitation gets a lot of notice: the two-dimensional (2D) nature of ICs. An IC, or chip, is flat. Its operating speed depends greatly on the length of the wires interconnecting its tiny components. Chip designers spend enormous resources to make the longest wire as short as possible and to reduce component size so they can be placed closer together. But as long as chips are 2D devices, wire length constrains how fast they can operate.

New Capabilities From Interconnected Chips

On a seemingly unrelated front, the need frequently arises for large electronic displays — in hospital operating rooms, military command centers, industrial applications and even sports bars. Sometimes the display must also be flat. For home use, a display that mounts flat on the wall like a picture is ideal and is much sought after by technology leaders. Large CRT (cathode-ray tube) displays are available. But a 35-inch CRT display may be 30 inches deep and weigh 150 pounds. Flat-panel displays, like those in notebook computers, are also widely available. But they are typically small, since the display usually has just one panel consisting of a single, broad, light-emitting IC. Attempts to greatly increase the scale of single-IC fabrication have been accompanied by commercially unacceptable levels of defects. Interconnecting several chips introduces other problems.

. . . raised $26.6 million from a second public stock offering in March 1993 . . .

One Technology for Two Major Needs

The Multi-Film Venture (MFV) — a partnership between MCC and Kopin Corporation (a small company spun off in 1984 from Lincoln Laboratory at the Massachusetts Institute of Technology) — used ATP funding to speed by two years the development of technology to address the needs for larger flat-panel displays and for shorter IC component connectors. The new technology can be used to join several broad light-emitting ICs into a single large display with no visible seam. It can also be used to join small ICs, stacked like a deck of cards, so that wire lengths can be shortened. ATP funding made this joint venture possible, and the project's success attracted further research and development funding from outside sources.

The new technology is based on ATP-funded development of advanced methods for positioning IC components with micron-scale alignment and for connecting individual ICs, as well as new adhesives procedures for bonding chips together. It is also based on proven IC fabrication methods and proprietary thin-film-transfer technology previously developed by Kopin. MCC contributed its expertise in adhesives, bonding and positioning.

During the ATP project, MFV researchers proved the feasibility of transferring thin-film, single-crystal silicon ICs to a substrate and interconnecting them to form a functioning multifilm module (MFM). They designed, built and successfully demonstrated a large-area, flat-panel display to show seamless joining of several panels (single, broad, light-emitting ICs) arranged side by side like floor tiles, to form the display.

Giant Flat Screens and 3D Microprocessors

The earliest commercial use of the new MFM technology is likely to be in military, medical and industrial flat-panel displays and large high-resolution displays. The tiled displays would replace conventional CRT displays. When cost considerations make it profitable, they would replace large single-panel displays based on relatively expensive technologies such as liquid crystal display. The new technology also has potential applications in desktop computer displays and — with volume production and lower prices — in wall displays for the home. In addition, the ATP technology should be competitive for very high resolution screens, those with resolutions of 2,000 by 2,000 pixels per inch up to 10,000 by 10,000 pixels.

. . . researchers proved the feasibility of transferring thin-film, single-crystal silicon ICs to a substrate and interconnecting them to form a functioning multifilm module . . .

The MFM process is expected to be useful for making devices with directly joined layers of ICs that perform different functions. In one application, Kopin is collaborating with Northeastern University (using $2 million from the Office of Naval Research) to design, fabricate and demonstrate a three-dimensional (3D) microprocessor.

In a second application, Kopin is working with Northeastern and Polaroid in a five-year project, begun in June 1996, to develop a 3D computational image sensor for compact low-power video cameras. The sensor will be a stack of three chips: a sensor IC, a computation IC and a read-out IC. The chips will be connected using the ATP-funded MFM technology. This project is supported by $5 million from the Defense Advanced Research Projects Agency.

. . . potential applications in desktop computer displays and — with volume production and lower prices — in wall displays for the home.

Although products incorporating the ATP-funded technology are not yet on the market, they are likely to arrive soon.

Kopin Succeeds in Capital Markets

Although products incorporating the ATP-funded technology are not yet on the market, they are likely to arrive soon. Kopin has shown that it can carry out commercialization plans, as evidenced by its introduction of other products after more than a decade of work on the underlying technology. Also, Kopin's success at raising funds in the private-capital market reflects investor confidence in the company's ability to commercialize its technology. Kopin has raised an additional $31.8 million via private equity investments since the end of the ATP project.

When the new products — flat-panel displays and 3D microprocessors — are introduced, intermediate companies (which purchase components produced by Kopin), final-product manufacturers and consumers are expected to reap large benefits from the ATP-funded technology.

PROJECT:

To show the feasibility of interconnecting thin-film integrated circuits (ICs), packed side by side or in layers, to form a complex, multifilm module (MFM), and to demonstrate this technology in a large flat-panel display.

Duration: 9/15/1992 — 9/15/1995
ATP number: 91-01-0262

FUNDING (IN THOUSANDS):

ATP	$2,776	48%
Company	2,973	52%
Total	$5,749	

ACCOMPLISHMENTS:

MFV developed the MFM technology and demonstrated it in a large, flat-panel display. In actions related to the project, Kopin:

- received two patents for project-related technology:

  "Single Crystal Silicon Tiles for Liquid Crystal Display Panels Including Light Shielding Layers"

  (No. 5,377,031: filed 8/18/1993, granted 12/27/1994),

  "Method for Forming Three-Dimensional Processor Using Transferred Thin-Film Circuits"

  (No. 5,656,548: filed 9/19/1995, granted 8/12/1997);
- raised $8.1 million from private sources during the ATP project;
- raised $26.6 million from a second public stock offering in March 1993;
- received (with Northeastern University) $2 million from the Office of Naval Research in June 1996 for R&D work, based directly on the ATP-funded MFM technology, to design and fabricate a 3D microprocessor;
- received (with Northeastern and Polaroid) $5 million from the Defense Advanced Research Projects Agency in June 1996 for R&D work — using the ATP-funded MFM technology — on 3D computational image sensors for compact low-power video cameras;
- raised $31.8 million via private equity investments since the end of the ATP project.

COMMERCIALIZATION STATUS:

Commercialization is expected within one or two years for products incorporating the 3D microprocessor technology. Large-area flat-panel displays based on the MFM technology are expected to be commercialized when their market develops.

OUTLOOK:

The outlook is very promising. Products based on the ATP-funded technology are being developed by Kopin and are expected to be introduced to the market soon.

COMPANIES:

Multi-Film Venture
(MFV; formerly The American Scaled-Electronics Consortium)

Kopin Corporation (joint venture lead)
695 Myles Standish Blvd.
Taunton, MA 02780

Contact: Ollie Woodard
Phone: (508) 870-5959

Number of employees:
70 at project start, 100 at the end of 1997

Other joint venture participant:
MCC, Inc. (formerly Microelectronics & Computer Technology Corporation.

Electronics

Nonvolatile Electronics, Inc. (NVE)

Computer RAM Chips That Hold Memory When Power Is Off

Conventional random access memory (RAM) computer chips record information written or copied into them by a computer, and they hold that data as long as electricity flows through the chips. Once the power is turned off, the information is lost unless it has been "saved" to a floppy disk or to the computer's hard disk, which hold data even when the power is off. Many computer users have learned this fact only after a power outage or other mishap suddenly erases the data they were working on. Program manuals and technical support staff repeatedly advise computer users to "save often."

The clean room at Nonvolatile Electronics in which GMR sensors and other devices are fabricated.

RAM That Remembers Without Power

If a memory chip could store data permanently, it would prevent these accidental loses of information. And if it could be produced in small sizes at competitive costs, the new chip would greatly affect how computers are configured and used. For example, an insertable card containing memory chips (which have no moving parts) could be substituted for a hard disk drive.

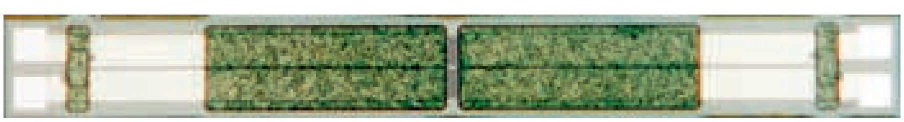
Civilian Use of MRAM Technology

This ATP project with Nonvolatile Electronics (NVE), founded in 1989 (and operated from the founder's house until the ATP award), aimed to develop such a memory chip. The founder co-invented "magnetoresistive" RAM (MRAM) technology for defense applications while at Honeywell, which subsequently licensed the technology to NVE for civilian uses. For these applications, the technology had to achieve greater density, signal strength and production yield to meet cost considerations, which are more important in consumer markets than in the military market.

A metal is magnetoresistive if it shows a slight change in electrical resistance when placed in a magnetic field. In 1988, scientists discovered that a sandwich of metals shows a much larger change in resistance than a single metal of the same size. This effect was named "giant magnetoresistance," or GMR.

GMR sensors have many applications . . .

Researchers at NVE saw the use of GMR materials as a way to achieve advances in signal strength, and they made important advances in the producibility of GMR materials. They also achieved the project's circuit density goals and made substantial improvements to production throughput, or yield. These developments are all important for lowering barriers to commercializing the technology for civilian applications. The researchers



Photomicrograph of a GMR magnetic field sensor, with actual dimensions of 436 x 3370 microns.

PROJECT:
To develop magnetoresistance technology for use in making computer random access memory (RAM) "nonvolatile" — data will not be lost when power is turned off.

Duration: 4/1/1991 — 3/31/1994
ATP Number: 90-01-0166

FUNDING (IN THOUSANDS):

ATP	$1,785	67%
Company	869	33%
Total	$2,654	

ACCOMPLISHMENTS:
In its quest to develop magnetoresistive RAM (MRAM), NVE made significant advances in producibility, circuit density and signal strength by using giant magnetoresistance (GMR) materials. In the process, the company developed an important spinoff application of the technology in sensors. Indicative of progress, NVE:

- started producing an initial commercial product, a GMR magnetic bridge sensor, in 1994, selling about 50,000 by the end of 1997 to other companies for examination purposes and earning revenues of more than $150,000 that year alone;
- entered into an agreement with Motorola in 1995 to develop MRAMs (development is still under way, with sales possible in 1999);
- entered into an agreement with Microtrace in 1996 to use a GMR-based procedure to make counterfeiting of aircraft parts much easier to detect (development work is under way);
- licensed the ATP-funded technology to Honeywell (for use in military and avionics applications), which incorporated it into computer systems placed in government agencies; and
- transferred knowledge about GMR materials to members of an ATP joint venture working on technology for magnetic disk storage based on the GMR effect.

COMMERCIALIZATION STATUS:
NVE is successfully making and selling — with a recent growth rate of about 3,000 percent — GMR-based sensing products, a spin-off from its MRAM technology development project. It is also pursuing commercialization of MRAMs through an agreement with Motorola, an endeavor that could lead to a substantial share of a $45 billion/year market.

OUTLOOK:
The outlook is excellent for expanded use of GMR sensors, which have many applications, including pace makers, engine control, shock absorbers, antilock brake systems, current monitoring, cylinder position sensing and automatic meter reading. The outlook for commercialization of the nonvolatile memory chips is potentially bright. But with several more years of development, the extent of use remains uncertain. Spillover benefits are potentially large.

COMPANY:
Nonvolatile Electronics, Inc. (NVE)
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Edina, MN 55436

Contact: James M. Daughton
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Number of employees:
10 at project start, 56 at the end of 1997

made prototype high-quality MRAM cells that were successfully demonstrated at Honeywell.

A Promising Spinoff Application

As NVE focused on GMR materials advances, it saw a potential spin-off application that received only marginal attention when the company started its ATP project: GMR sensors. A major application for sensors based on the new technology is possibly in antilock brake systems in automobiles and trucks. These systems use a clamp to grip the edge of a steel disk attached to the wheel. If the clamp grabs too tightly, the brake "locks," the wheel stops rotating, and the tire slides on the road surface instead of gripping it. In an antilock brake system, a sensor detects the rotation of the disk and feeds that information into a computer. If the computer detects overly rapid deceleration — indicating the brake is about to lock — it directs the braking mechanism to reduce clamp pressure to keep that from happening.

The new NVE sensors are substantially more sensitive than conventional sensors. They can be farther from the monitored object while performing equally well. Their magnets can be smaller, so the cost is less. And the NVE sensors can detect rotational speeds closer to zero, which means the computer receives more-accurate data to use in controlling the brake mechanism. In a vehicle equipped with an antilock brake system incorporating NVE sensors, the driver will have better skid and stopping control.

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Product Sales and Commercialization Agreements

NVE expects to apply its sensor technology in several other industries, too, including medical devices, consumer products and machine tool manufacturing. Production for these markets is planned for the near future. According to NVE, it is the first to make and sell GMR-based sensing products for the general market, and it has established a new company division for this purpose. Its sales of GMR-based sensors have grown by about 3,000 percent recently, from around $5,000 in 1994 to more than $150,000 in 1997. The company has also generated revenues from engineering contracts, as well as royalties from companies that license its technology.

NVE entered into an agreement with Motorola in 1995 to develop MRAMs, and the development work is under way. Production could begin in 1999. If this effort succeeds, NVE expects to capture a sizable share of the $45 billion annual market for memory and hard-disk-drive products. The company also signed an agreement with Microtrace in 1996 to use a procedure based on GMR techniques to make counterfeiting of aircraft parts much easier to detect. The development work is under way, and products for this application are also expected in 1999.

For GMR applications beyond its own pursuits, NVE has offered its knowledge to other companies, universities and national

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laboratories. This was done through another ATP project (#91-01-0016: "Ultrahigh-Density Magnetic Recording Heads") conducted by a large joint venture led by the National Storage Industry Consortium. NVE officials consulted on fabrication methods for making GMR films and supplied samples of the films made by NVE.

Benefits From the Technology

Because NVE is selling only sensors, all benefits will initially come from that product. When the sensors actually begin appearing in commercial products — some time after the year 2000 — end users will have access to competitively priced devices that operate at much greater temperature extremes than do conventional sensors. Additional benefits will accrue from GMR sensors as more are used in a variety of applications.

GMR sensors will likely generate substantial economic benefits beyond those realized by NVE. A sensor is a small part of an antilock brake system, which is a small part of a much larger device — an automobile. Several manufacturing and subassembly stages lie between the development of the sensor and the final product, and the sensors add value to the product at each stage. According to NVE, the total of this spillover benefit will likely be more than 10 times greater than what the company earns for the use of its new technology. And the aggregate benefit will increase as more cars are equipped with antilock brake systems incorporating NVE sensors. Spillover benefits promise to be even larger when the sensors are used in other applications.

In addition to these applications, the company's GMR sensors are being used for portable traffic monitoring instruments, and they may be very useful for instruments used to detect land mines. Geometrics, Inc., in Denver, Colorado, has contracts to design and test devices to detect anti-personnel mines for the U. S. military, and it has subcontracted with NVE to supply GMR sensors for the detectors. If the design and testing lead to workable detection instruments, a much better job of finding and removing unwanted land mines will be the result. There are 100-200 million such land mines throughout the world in areas that were formerly areas of warfare, and they kill and maim tens of thousands of innocent people each year.

The market for MRAMs — the application initially targeted by NVE — may eventually be important, but it is still in the future. If MRAMs ultimately reduce accidental loss of information to computer users, benefits will be large.

ATP Project Saves Company

Before the ATP project, NVE was a tiny, undercapitalized company facing significant technological risks in developing the technology for commercial uses. Funding from the ATP, however, enabled the project to be done and prevented the company from failing, NVE officials say. In addition, the ATP award improved the company's ability to attract capital from other sources.

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Spire Corporation

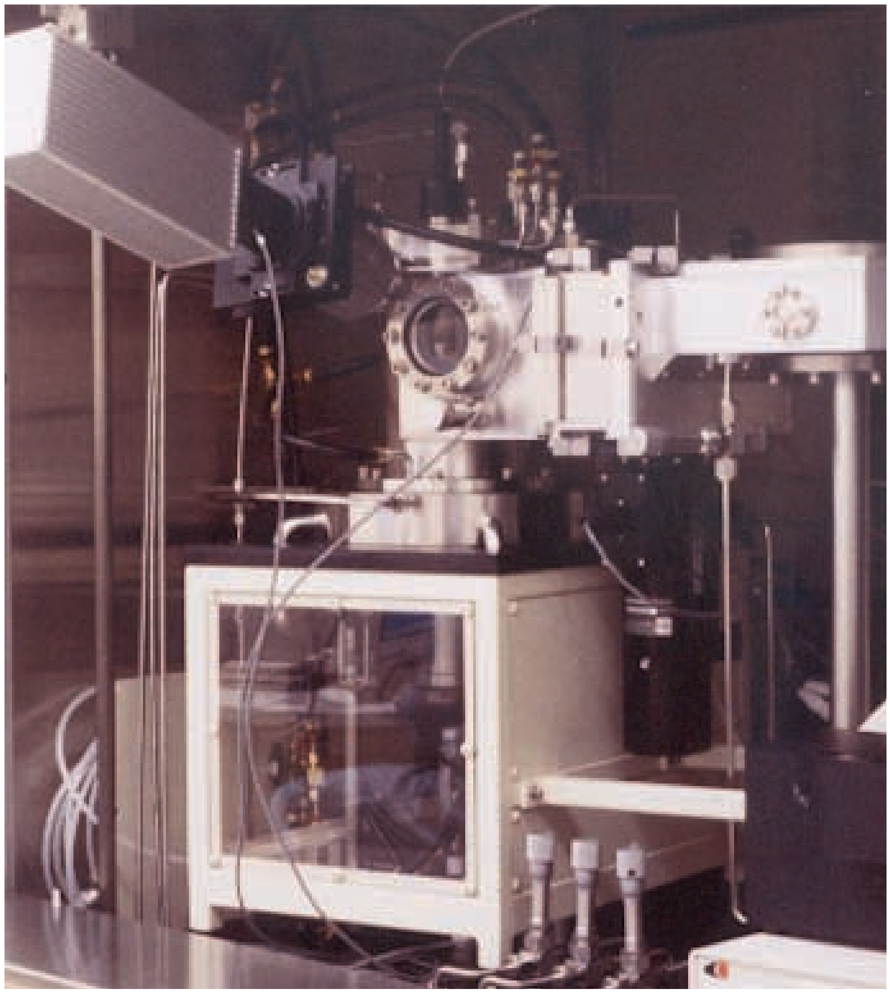
A Feedback-Controlled, Metallo-Organic Chemical Vapor Deposition Reactor

Laser diodes are the tiny workhorses in many industrial and consumer products. Every CD-ROM player has at least one, and many printers and photocopiers have a large array of them. More than 20 million laser diodes are needed each year for this market alone, and the number is growing.

Advanced Fabrication Control for Improved Electronic Devices

This ATP project with Spire Corporation developed a new way to make laser diodes and other optoelectronic devices. Founded in 1969, Spire is a specialty manufacturer of semiconductor wafers and metallo-organic chemical vapor deposition (MOCVD) equipment. The company's new method makes possible the manufacture of individual lasers and laser arrays at lower cost and with higher performance characteristics.

Spire built and demonstrated an advanced MOCVD reactor designed for the fabrication of laser diodes. Laser diodes are intricate multilayer structures generally grown by MOCVD on compound semiconductor wafers. Researchers developed in-process sensors to monitor the development of layers on the substrate, as well as control systems to automatically adjust the many process parameters. They demonstrated that the new technology can control the growth rate of the layers. They also showed that the new reactor performed better than conventional reactors in terms of epitaxial layer uniformity over the entire wafer, as well as run-to-run consistency. These two factors can contribute significantly to reducing the cost of making laser diodes.

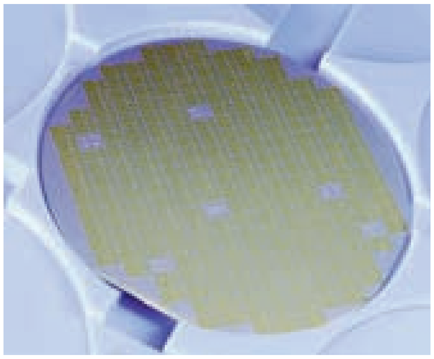


The advanced metallo-organic chemical vapor deposition reactor constructed with funding from the ATP.

Potential for Commercial Products

The project did well technically, and limited commercialization is under way. Spire is pursuing its original plan to produce and sell reactors and license the technology to other manufacturers, and it is in discussions with several potential customers. The company also planned to produce low-cost laser diode arrays

. . . planned to produce low-cost laser diode arrays in competition with foreign producers, but that market did not develop.



A wafer populated with arrays of vertical cavity surface emitting lasers.

The company's new method makes possible the manufacture of individual lasers and laser arrays at lower cost and with higher performance characteristics.

PROJECT:
To develop an advanced feedback-controlled, high-throughput, metallo-organic chemical vapor deposition (MOCVD) reactor for fabricating low-cost, high-quality laser diode arrays.

Duration: 6/15/1992 — 3/31/1995
ATP number: 91-01-0263

FUNDING:

ATP	$1,223	56%
Company	973	44%
Total	$2,196	

ACCOMPLISHMENTS:
Spire achieved the project's research goal and afterward conducted additional, company-funded development to commercialize the technology. A prototype reactor is being used for commercial wafer production and customer-specific development work. Signs of the project's success include the fact that the company:

- published four papers and presented several others at professional conferences during the award period;
- demonstrated the ability to grow epitaxial wafers with high-quality uniformity of composition and thickness over an entire wafer 2.25 inches in diameter;
- demonstrated the ability to fabricate vertical cavity surface emitting lasers (VCSELs) with state-of-the-art performance characteristics;
- published a 1997 update on use of the ATP-funded reactor, "In Situ Monitoring and Control for MOCVD Growth of AlGaAs and InGaAs," in the *Journal of Electronic Materials*;
- received $356,000 from two large manufacturers for development of advanced VCSEL epitaxial wafers and wafer production processes, with an additional $450,000 to $750,000 expected in the near future; and
- expanded sales of commercial epitaxial wafers (mostly for lasers and light-emitting diodes), with sales revenue of about $200,000 in 1998.

COMMERCIALIZATION STATUS:
Limited commercialization has been under way since 1996. The ATP-funded technology has been incorporated into an MOCVD reactor being used for commercial production of optoelectronic epitaxial wafers. These include VCSEL epitaxial wafers that are being developed for high-speed laser printing. Spire is also using the reactor for two development projects funded by other companies.

OUTLOOK:
Spire expects to produce substantial numbers of VCSEL devices in the future. Because the market is growing rapidly, the company is positioned to exploit its superior in-house epitaxial wafer growth capability, based on the ATP-funded technology, to produce large quantities of whole epitaxial wafers, as well as wafers processed into optoelectronic devices ready for packaging.

COMPANY:
Spire Corporation
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Bedford, MA 01730-2396

Contact: Harvey B. Serreze or Kurt J. Linden
Phone: (781) 275-6000

Number of employees:
180 at project start, 150 at the end of 1997

in competition with foreign producers, but that market did not develop.

Spire has successfully used the prototype reactor to perform customer-specific research and development and to produce epitaxial laser wafers of a demanding structure. One customer has invested more that $250,000 with Spire to develop vertical cavity surface emitting laser (VCSEL) wafers and plans to invest another $450,000 in the effort in the near future. A VCSEL emits light in a cylindrical beam vertically from its surface and may offer significant advantages over edge-emitting lasers in some applications. This customer may also buy an MOCVD reactor from Spire in the next two years, following completion of the initial development project.

Spire is focusing on use of the new feedback-controlled reactor for growing laser wafers for VCSELs and edge-emitting lasers. VCSELs would be used in high-speed laser printers and in optical interconnects for computer links, and edge-emitting lasers would be used in solid-state laser pumps and in measurement and material processing applications. The company contracted with another large manufacturer in late 1997 to develop VCSEL arrays for advanced optical computer interconnects. Spire has already been paid $106,000 for the project and could potentially receive another $300,000. If the development work succeeds, Spire believes it will enable the company to enter the huge market for optical interconnect components.

ATP Project Opens Doors

If the ATP funds had not been available, Spire would not have done the project, company officials say. The ATP award enabled Spire to overcome technical barriers to volume production of VCSEL wafers, some of which contain more than 650 epitaxial layers. These complex structures had been previously grown only in a few laboratories and in small lots and sometimes virtually by hand. Spire's new capability, in turn, has attracted an entire new line of customers.

The potential for alliances with research and development partners is now high, and Spire is already working on advanced device development projects with several companies. The benefits to users of new devices made from these complex wafers can be significant. The ATP-funded reactor enables production of many kinds of wafers at lower costs. It also enables the production of some devices, made from VCSEL wafers, that could not be fabricated any other way. The benefits, however, can occur only if the company's limited commercialization expands into full-scale success, and it is still too early to tell whether that will happen.

Thomas Electronics, Inc.

Flat Fluorescent Lamps for Displays

Every cockpit in a large airplane contains small windows that are mainly used when the plane is on the ground. While flying, pilots "see" the world not by looking out the windows, but by looking at the text and images shown by instrument displays mounted on the walls of the cockpit. The quality of these images bears directly on the quality of the flying.

More-Visible Instrument Displays for Safer Flying

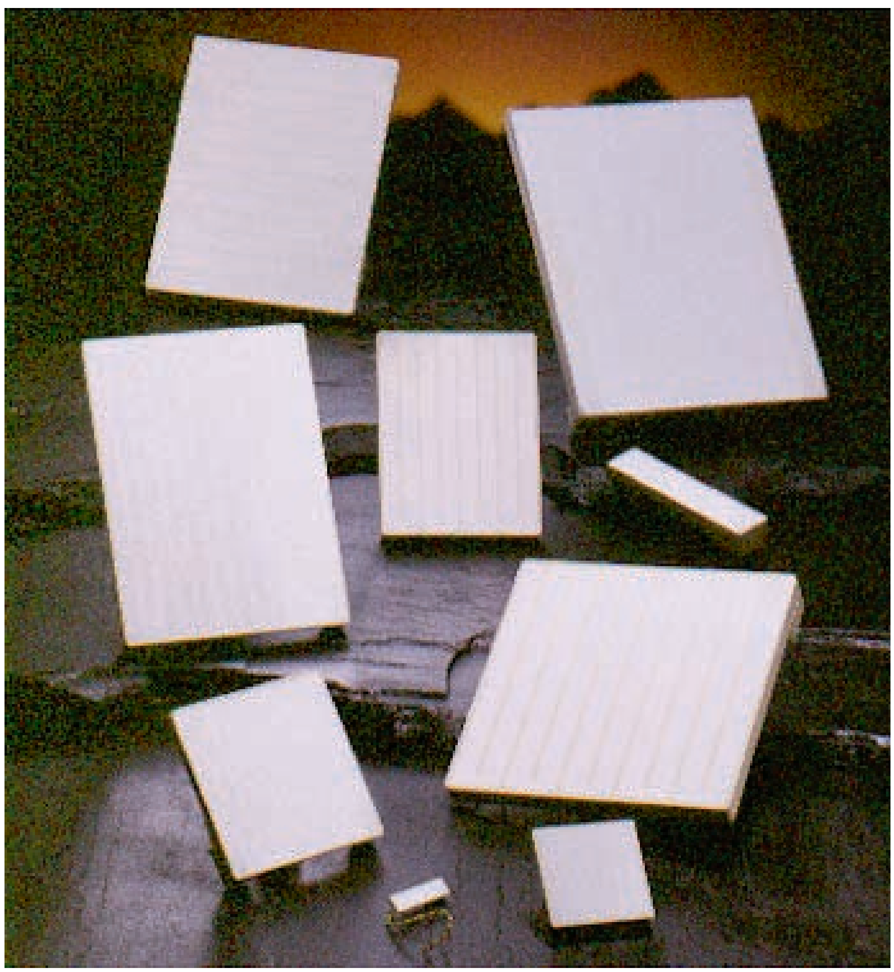
Today, almost every cockpit display uses cathode ray tube (CRT) technology. CRTs are a proven technology, have a long history and are fabricated by Thomas Electronics — which undertook this ATP project — for use in the manufacture of cockpit displays. CRT displays have a well-known drawback, however: the surface is glass, and the view one gets through it depends on the amount of light in the cockpit and the direction the light is coming from. In some circumstances, such as bright sunlight, visibility of displays may be seriously diminished.

Creating a Flat Fluorescent Lamp

Liquid-crystal displays (LCDs) — the flat-panel displays used in notebook computers — would be a good alternative to CRT displays. The drawback to LCDs, however, is that their light source is not nearly bright enough for use in airplane cockpits. This ATP project addressed that problem by developing the technology needed to make a flat, bright fluorescent lamp for backlighting an LCD. The new lamp would be about a quarter of an inch thick, have the same length and width as the LCD, and be attached to its back.

In conventional fluorescent lamps, a cathode discharges electrons that excite mercury vapor to emit ultraviolet light that, in turn, induces the phosphor coating on the interior of the lamp to glow white. Flat fluorescent lamps were not developed earlier because of the diffi-

In some circumstances, such as bright sunlight, visibility of displays may be seriously diminished.



Flat fluorescent lamps for flat panel display back-lighting, in a variety of sizes, ranging from 1.5 inches to 12.5 inches on the diagonal.

Flat fluorescent lamps were not developed earlier because of the difficulty in generating a bright plasma in the thin space between wide, flat sheets.

PROJECT:

To develop a high-efficiency electron source for fluorescent lighting to enable a new class of efficient, bright, flat lamps with wide applications in computer and instrument displays, high-definition TV displays and wide-area ultraviolet light sources for industrial use.

Duration: 2/1/1994 — 1/31/1997

ATP number: 93-01-0109

FUNDING (IN THOUSANDS):

ATP	$718	77%
Company	215	23%
Total	$933	

ACCOMPLISHMENTS:

Thomas developed the high-efficiency electron source needed to construct flat fluorescent lamps, which was the goal of the project. The company achieved the following:

- entered pilot production of flat lamps for key customers in the U.S. display industry;
- received orders for further evaluation and field testing of the new technology in cockpit applications from Optical Image Systems, AlliedSignal, Honeywell, Litton Industries, Kaiser Electronics and five other companies; and
- placed prototypes with three military contractors for rugged displays in tanks and other ground vehicles.

COMMERCIALIZATION STATUS:

Current sales of prototypes and pilot models of flat fluorescent lamps to avionics customers range from 30 to 50 units per month. If customer tests prove the technology works for them, regular commercial sales are expected to begin after the flat-panel displays have been certified by the Federal Aviation Administration for use in cockpits.

OUTLOOK:

Full commercialization is expected after refinements to the technology based on feedback from customers using prototype units. If the technology is commercialized, its users — aircraft manufacturers, airlines and their passengers — will benefit from brighter, more reliable and cheaper backlights for flat-panel displays in airplane cockpits.

COMPANY:

Thomas Electronics, Inc.
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Wayne, NJ 07470

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Number of employees:
251 at project start, 324 at the end of 1997

Informal collaborator:
Princeton University

culty in generating a bright plasma in the thin space between wide, flat sheets. Conventional cathodes are too inefficient to create enough light for the color LCDs used in avionic displays. And although barium dispenser cathodes (BDCs) are efficient enough for the task, they were never used in the presence of mercury, which is believed to "poison" the barium and quickly reduce both the efficiency and life span of the device. Thomas solved the mercury problem with BDCs by using a new hollow-cathode design that enabled the company to construct a truly flat fluorescent lamp.

In addition, Thomas introduced new materials to flat fluorescent lighting. The front of the lamp is glass. But the back is hardier ceramic material and has all the light-producing components embedded in it. The ceramic back enables the lamp to withstand severe shock and vibration much better than if both sides were glass. In addition, the thermal properties of the ceramic material allow the lamp to operate at significantly higher temperatures than comparable lamps made solely of glass. As a result, these new lamps can be used for rugged flat-panel displays in applications such as military tanks.

Field Testing Underway

Follow-on research and development work is on track to meet the project's commercialization goal — the introduction into commercial and military airplane cockpits of flat-panel displays containing the new fluorescent lamp. To date, Thomas has invested more of its own money in the effort than it received from ATP, and the work is beginning to pay off. The company is completing a pilot production plant and has received orders for further evaluation and field testing of the new technology from Optical Image Systems, AlliedSignal, Honeywell, Litton Industries, Kaiser Electronics and five other companies. The field testing must yield positive results before the Federal Aviation Administration will certify the flat-panel displays for use in cockpits.

About 10,000 displays are installed in airplane cockpits each year. Compared with CRT devices, the new flat-panel displays will be more effective (they produce more light), more reliable (the ceramic material is hardier than glass) and less-costly (the ceramic material can be machined more easily than glass). Ultimately, their use is expected to benefit aircraft passengers, who will enjoy safer air travel because pilots have more-effective, more-reliable instrument displays. It is also expected to benefit flat-panel display manufacturers, aircraft manufacturers and airlines through cost reductions and quality improvements.

Potential uses for the flat-lamp technology include displays in military ground vehicles, such as tanks. Displays in these applications must withstand greater extremes in vibration, temperature and other operating conditions than ordinary displays. Three companies specializing in such displays have ordered flat-lamp prototypes from Thomas.

ATP Bolsters U.S. Technology

Without the ATP award, Thomas officials say, the company would not have done the research and development work for this project. The company would have struggled along with its conventional CRT technology and would have stood virtually no chance of competing with other display-component suppliers, all of which are foreign companies. In addition, the award helped Thomas establish connections with scientists at Princeton University and form alliances with contractors.

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